LA-13606-PR Progress Report
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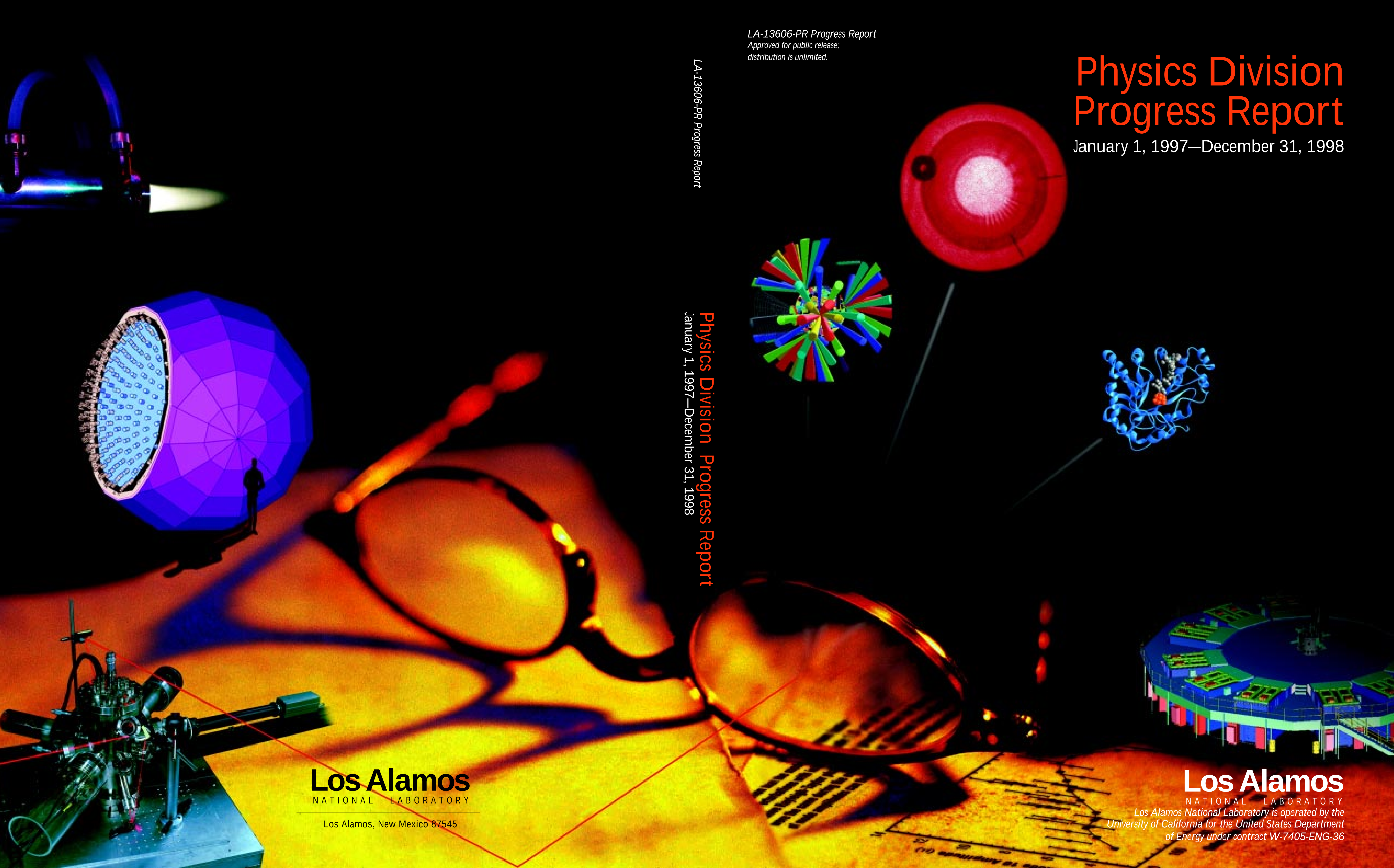
Physics Division Progress Report

January 1, 1997—December 31, 1998



Los Alamos
NATIONAL LABORATORY
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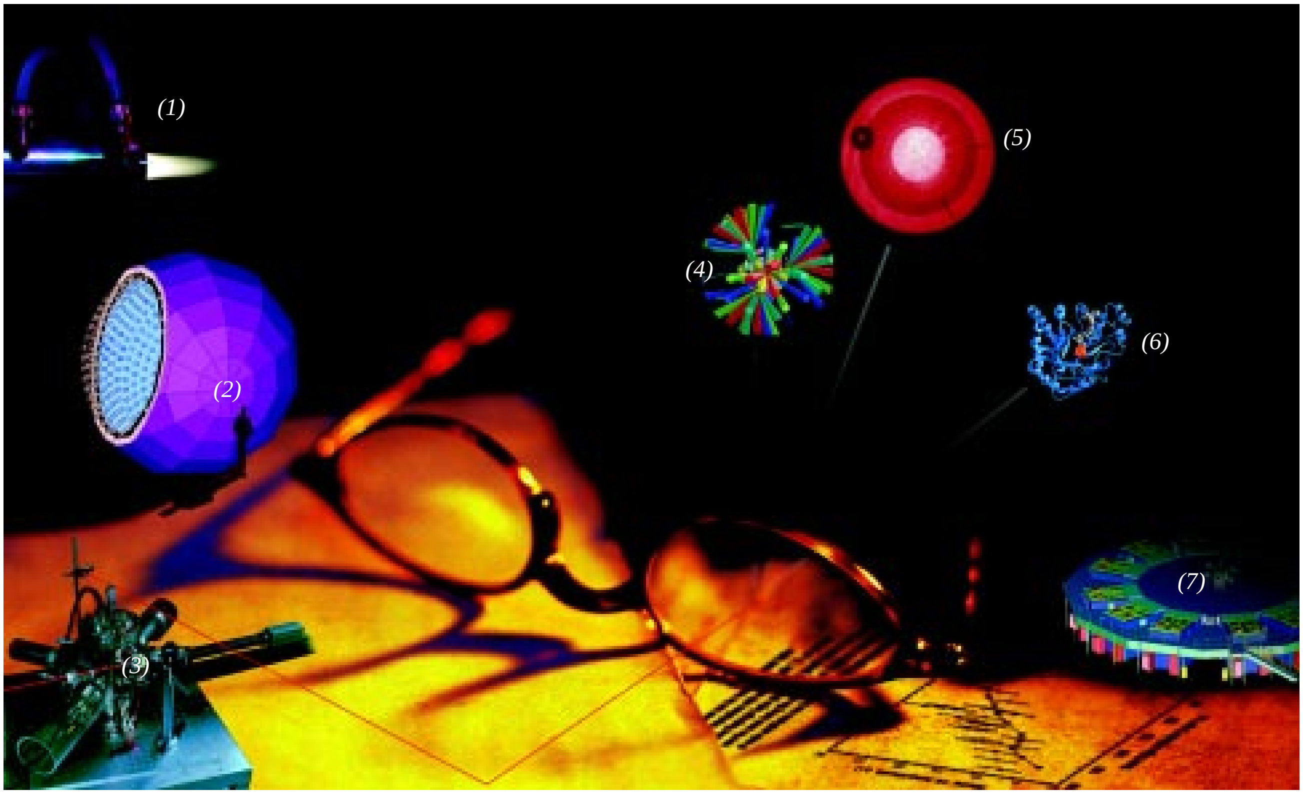
January 1, 1997—December 31, 1998

Los Alamos
NATIONAL LABORATORY
Los Alamos, New Mexico 87545



On the cover:

This cover design illustrates the wide and diverse range of projects that we pursue in the Physics Division:

(1) We developed the atmospheric pressure plasma jet, a novel tool for removing surface contaminants from target objects. Applications include neutralizing chemical and biological contaminants and removing graffiti.

(2) In collaboration with Fermilab, our Booster Neutrino Experiment (BooNE) will use an oil-filled sphere lined with 1,220 phototubes to observe the tiny light flashes that accompany neutrino oscillations. Such oscillations would mean that neutrinos have mass, and would change the way we view the composition of the universe.

(3) We are developing a technique for quantum computation using laser manipulation of cold, trapped atoms. Using an apparatus like this, we have succeeded in trapping calcium ions that may serve as the basic quantum-mechanical bits.

(4) We are exploring various designs for radiation cases, or hohlraums, that might be used to achieve thermonuclear ignition at the National Ignition Facility. This image shows a spherical hohlraum with tetrahedral symmetry, which will allow implosion experiments at NIF-relevant energies. The graph on the page alludes to experiments exploring hydrodynamic instabilities in cylindrical hohlraums.

(5) To refine the models used to calculate weapons performance, we study imploding liners at the Pegasus Pulsed-Power Facility. This radiograph shows a liner 3.38 microseconds after implosion. Visible are material that has broken free from the target during the implosion, and jets of aluminum seeded by grooves machined on the target's surface.

(6) We are collaborating with the Life Sciences Division on the Structural Genome Project, a nationwide effort to achieve a comprehensive understanding of three-dimensional protein structures. Protein cartoons like this allow researchers to visualize protein structures and their functions, a major step toward a complete understanding of the machinery of life.

(7) The future Atlas Facility will provide 23-MJ of pulsed-power for science-based stockpile stewardship and basic scientific research. The Atlas capacitor bank, shown, will be housed in 12 oil tanks arranged around a central target chamber. Atlas is expected to generate its first pulse in 2001.

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Progress Report

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Physics Division Progress Report

January 1, 1997–December 31, 1998

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Los Alamos
NATIONAL LABORATORY

Los Alamos, New Mexico 87545

Physics Division Progress Report
January 1, 1997–December 31, 1998

Abstract

This issue of the Physics Division Progress Report describes our progress and achievements in applied and basic science during calendar years 1997 and 1998. The report covers the activities of the five Physics Division groups, which represent the main areas in which we serve Los Alamos National Laboratory and the nation: Biophysics, Hydrodynamic and X-Ray Physics, Neutron Science and Technology, Plasma Physics, and Subatomic Physics. This report includes a message from the Physics Division director, general information about the mission and organization of the Division, descriptions of the activities of each of our groups, highlights of major research efforts throughout the Division, descriptions of the individual projects we support, our staffing and funding data for the subject years, and a list of our publications and conference presentations.

Contents

Introduction

Message from the Division Director 2
Mission and Goals 4
Organizational Chart 5

I. Group Descriptions

P-21: Biophysics 8
P-22: Hydrodynamic and X-Ray Physics 18
P-23: Neutron Science and Technology 24
P-24: Plasma Physics 32
P-25: Subatomic Physics 46

II. Research Highlights

The Birth of Structural Genomics 56
Bayesian Inference Applied to the Electromagnetic Inverse Problem 62
Design and Preliminary Results from a High-Temperature SQUID Microscope for Nondestructive Evaluation 70
CYRAX™: A Portable Three-Dimensional Laser-Mapping and Imaging System 76
Remote Ultralow-Light Imaging 80
High-Energy-Density Physics at the Pegasus-II Pulsed-Power Facility: 1997–1998 84
Subcritical Plutonium Experiments at the Nevada Test Site 94
Fundamental Symmetries with Magnetically Trapped ^{82}Rb 102
Advances in Quantum Computation 106
Practical Free-Space Quantum Key Distribution 110
"Interaction-Free" Measurements: The In's and Out's of Quantum Interrogation 116
Plasma Source Ion Implantation Research, Development, and Applications 122
Convergent Hydrodynamics of Inertial Confinement Fusion Implosions 132
Trident Research Campaigns 146
Development of an Infrared Imaging Bolometer 154
Proton Radiography 160
Looking for Antiquarks in Nuclei 166

III. Project Descriptions

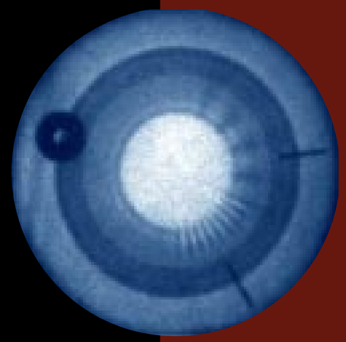
P-21: Biophysics 174
P-22: Hydrodynamic and X-Ray Physics 179
P-23: Neutron Science and Technology 187
P-24: Plasma Physics 197
P-25: Subatomic Physics 207
P-DO: Physics Division Office 215

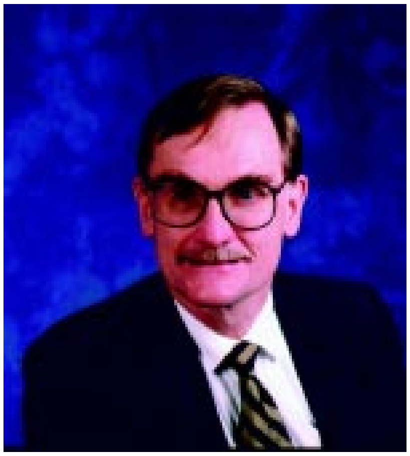
Appendix A. Physics Division Funding and Personnel Data, FY97–FY98 220

Appendix B. Publications and Conference Presentations 224

Introduction

The future Atlas Facility will provide 23-MJ of pulsed-power for science-based stockpile stewardship and basic scientific research. The Atlas capacitor bank, shown here, will be housed in 12 oil tanks arranged around a central target chamber. Each tank will contain up to two removable maintenance units and up to 32 capacitors. The entire structure will be 14 feet high and 80 feet in diameter. Atlas is expected to generate its first pulse in 2001. The image below shows a radiograph from a liner experiment at the Pegasus facility exploring material that spalls, or breaks free, from the target surface during the implosion. Data from such experiments allow us to test computational models. Atlas will allow us to conduct such experiments at much higher energy densities over a larger material volume.





Physics Division personnel have achieved significant progress in research and development during the past two years. This progress report recounts the work of the Division during this creative and productive period as we supported Laboratory missions and goals in the areas of both basic and applied science.

The mission of the Physics Division is to further our understanding of the physical world, to generate new technology in experimental physics, and to establish a physics foundation for current and future Los Alamos programs. The work described and the publications cited in this report demonstrate the degree to which we have been able to implement this mission. The five main areas of experimental research and development in which Physics Division serves the needs of Los Alamos National Laboratory and the nation are (1) biological physics, (2) hydrodynamic physics, (3) neutron science and technology, (4) basic and applied plasma physics, and (5) subatomic physics.

This report includes Division goals, organizational structure and group summaries, selected research highlight articles, project descriptions, staffing and funding levels for FY97–FY98, and a list of publications and presentations by Physics Division authors. The research capabilities reflected here are based on the very broad array of talents and interests of the more than 300 physicists, engineers, and technicians who contribute to this enterprise. From our senior scientists and technicians to our experienced support staff, to our newest staff, postdocs, and students, this corps of talented individuals is our most important resource. Our staff's dedication to excellence, creativity and ingenuity, and relentless pursuit of scientific understanding are the fundamental drivers of our Division's success.

Additionally, we are empowered with a critical set of facilities that we operate and/or use. The latter include the proton and neutron capabilities of the Los Alamos Neutron Science Center (LANSCE) accelerator facility, the Pegasus II and Atlas pulsed-power facilities, the Trident laser complex, and several large plasma-generation devices. We also perform extensive experimental work at off-site facilities, including the underground containment facilities in Nevada, large beamline and detector facilities at the Fermi National Accelerator Laboratory (Fermilab) and Brookhaven National Laboratory, and gamma-ray and x-ray beamlines also at Brookhaven. Our work is not confined to domestic facilities. We are involved with experiments in Russia and states of the former Soviet Union, at the European Laboratory for Nuclear and Particle Physics (CERN) in Switzerland, at the Atomic Weapons Establishment (AWE) in the United Kingdom, with the Japan Atomic Energy Research Institute (JEARI), and with a host of other foreign collaborations. Finally, new projects are continuously being created in the Division. For example, we are evaluating the research impacts of an improved laser facility and a proton-radiography facility. We are dedicated to accomplishing all of this in a manner that protects the health and safety of our employees, the public, and the environment.

In addition to the wealth of productive collaborations with university and other government laboratories, industrial partnerships continue to be important to Physics Division. Over the past decade, we have established an extensive national network through cooperative and contract research, user facility agreements, scientific staff exchanges, and licensing. In the area of plasma science and particle beams alone, Physics Division performed meaningful work with over 50 companies, ranging from small start-ups in northern New Mexico to Fortune 500 corporations. Locally, we created an environment that enabled the creation of two new small businesses and attracted three industrial staff members for long-term residence at our facilities. In the past two years, our collaborative efforts have earned three prestigious R&D 100 Awards. In addition to their scientific content and economic impact, our industrial collaborations create a valuable network in which we can discuss human resource and operational issues such as environment, health, safety, security, finance, and intellectual property management.

Physics Division has also been a responsible neighbor to the Northern New Mexico community. In addition to the regional economic development that results from industrial partnerships, we initiated a well-received educational outreach program in 1998. Through this program, members of our technical staff visit Santa Fe high schools to present lectures and demonstrations. This allows us to transmit some of our enthusiasm for our recent research to the next generation of scientists and citizens. Through such outreach, we are able to tie our work to the subjects students study in their classes, conveying the greater implications of scientific study, as well as the imagination and excitement behind our work.

As you browse through this report, I hope that you will gain an understanding of who we are and what we do and that you will share my enthusiasm for the research it contains. If I can provide assistance or answer questions, please contact me.

Peter D. Barnes

Peter D. Barnes, Director
Physics Division

Mission and Goals

The mission of Physics Division is to further our understanding of the physical world, to generate new technology in experimental physics, and to establish a physics foundation for current and future Los Alamos programs.

The goals of Physics Division are to

- provide the fundamental physics understanding supporting Laboratory programs;

- investigate the basic properties of nuclear interactions, high-energy-density and hydrodynamic systems, and biological systems with a view toward identifying technologies applicable to new Laboratory directions;

- identify and pursue new areas of physics research, especially those to which the unique capabilities of the Laboratory may be applied;

- explore interdisciplinary areas of scientific endeavor to which physical principles and the methods of experimental physics can make an important contribution; and

- maintain strength in those disciplines that support the Laboratory mission.

Physics Division pursues its goals by

- establishing and maintaining a scientific environment that promotes creativity, innovation, and technical excellence;

- undertaking research at the forefront of physics with emphasis on long-term goals, high risks, and multidisciplinary approaches;

- fostering dialogue within the Division and the scientific community to realize the synergistic benefits of our diverse research interests;

- encouraging the professional development of each member within the Division; and

- conducting all of its activities in a manner that maintains a safe and healthful workplace and protects the public and the natural environment.

P. D. Barnes
Division Director

D. J. Rej
Deputy Division Director

J. B. McClelland
Deputy Division Director

P. R. French
Chief of Staff

Program Development

DOD/NIS	*J. Mack*
Industrial Partnership	*D. Coates*
Nuclear Physics	*Vacant*
NWT	*Vacant*

Atlas Project
Technical Director R. B. Miller

Operations Manager
S. Hadden

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ES&H Officer
S. Greene

Administrative Specialist
A. L. Hoerr

Executive Office Admin.
Vacant

Business Team Leader
R. Follmer (BUS)

HR Generalist
K. Haggart

P-21 Biophysics
C. C. Wood

P-22 Hydrodynamic and X-Ray Physics
J. S. Ladish
J. S. Shlachter

P-23 Neutron Science and Technology
M. Y. Hockaday
S. J. Seestrom

P-24 Plasma Physics
K. F. Schoenberg
J. C. Fernández

P-25 Subatomic Physics
A. P. T. Palounek*
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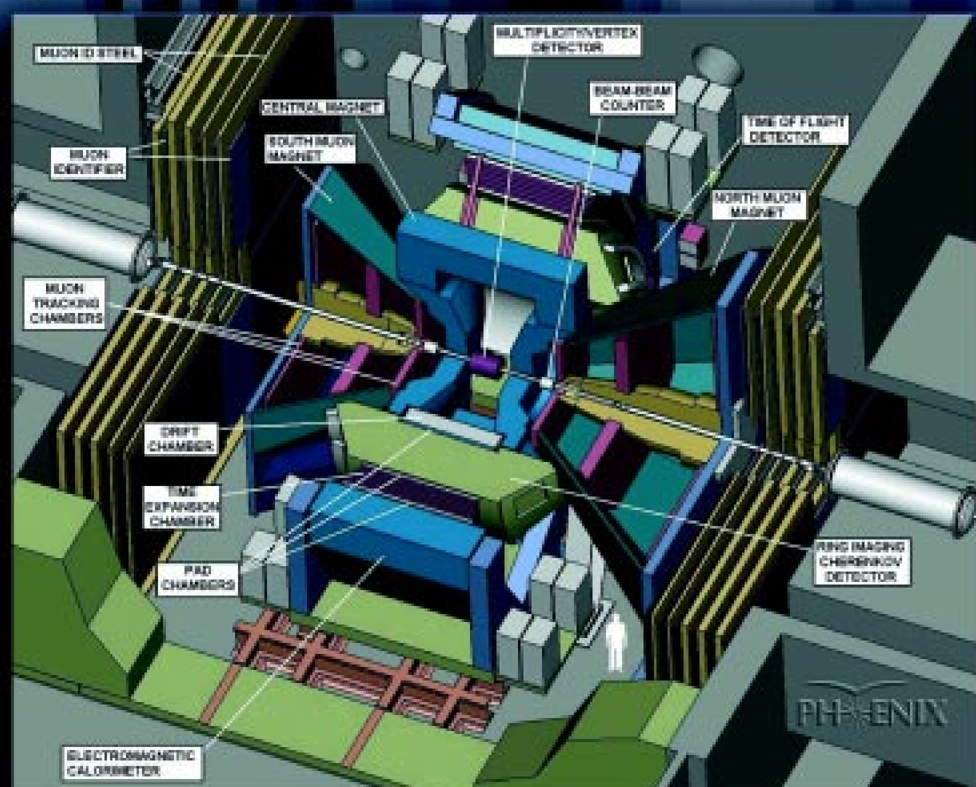
1. Group Descriptions



Physics Division has a major role in constructing two major subsystems for the Pioneering High Energy Nuclear Ion Exeperiment (PHENIX) detector at Brookhaven's Relativistic Heavy-Ion Collider (RHIC): the multiplicity/vertex detector and the muon subsystem. Both of these systems play crucial roles in the RHIC physics agenda, which aims to explore the exotic properties of quark-gluon plasmas like those that existed early in the evolution of the universe.

P-21: Biophysics

C. C. Wood, Group Leader

Introduction

The Biophysics Group (P-21) was founded in 1988 with the goal of applying the scientific and technical resources of Physics Division to the biosciences. Our mission is to contribute to an understanding of biological phenomena by means of the scientific, technical, and conceptual resources of physics; to use biological systems to elucidate general physical principles underlying complex phenomena; and to apply, where appropriate, our scientific and technical capabilities to core Laboratory programs.

Just as the 20th century is regarded as the century of the physical sciences, the 21st century will likely become the century of the biological sciences. P-21 and biophysics as a discipline are well-positioned to contribute to this biological revolution-in-progress through our emphasis on understanding biological systems using the scientific, technical, and conceptual resources of physics.

Many of the achievements of science to date have come from a reductionist strategy, in which scientists attempt to decompose the object under study into ever simpler components and to understand those components with ever increasing quantitative precision. Physics has been particularly successful in this regard. In contrast, much of biology has traditionally been less quantitative and more descriptive in character, both because biological systems are so complex and because some of the key explanatory concepts lie at a more abstract level. Examples of such complex phenomena include coding and processing of genetic information by DNA, and information representation, coding, and processing by the nervous system. However, recent advances in biophysical measurement and in molecular biology are beginning to allow detailed physical understanding of biological phenomena that were previously understood only in qualitative terms.[1] P-21 is well placed by virtue of its capabilities and research interests to contribute significantly to this important trend in the biosciences.

In addition to the goal of achieving a physical understanding of biological phenomena, research in P-21 shares a number of other common characteristics. Specifically,

- we investigate the relationships between structure, dynamics, and function of biological phenomena over a wide range of scales (*e.g.*, from biomolecules through the human brain);
- we make extensive use of detection, imaging, and reconstruction techniques (*e.g.*, x-ray crystallography, single molecule electrophoresis, magnetic resonance imaging [MRI], and magnetic field measurements using technologies based on superconducting quantum interference devices [SQUIDs] as shown in Fig. 1);
- we attempt to achieve a detailed interplay between high-resolution physical measurement and large-scale computational modeling and analysis of complex systems;

- we develop new facilities in support of our scientific and technical goals, including a dedicated x-ray beam line for protein crystallography at the National Synchrotron Light Source (NSLS) at Brookhaven National Laboratory, a large-bore MRI facility, a high-speed electronics laboratory and fabrication facility, and a growing SQUID applications laboratory at Los Alamos;
- we depend heavily on the tight connection and daily interplay between biologists and physical scientists within the group, the division, and the Laboratory; and
- we apply the knowledge, techniques, and capabilities developed in our biological studies to problems of national security and those of specific interest to the Laboratory when our ongoing efforts can offer unique solutions and significant mutual benefit.

During the past two years, P-21 had a number of major accomplishments, including the addition and rapid integration of the world-class high-speed electronics team previously in the Hydrodynamics and X-Ray Physics Group (P-22), winning two of the Laboratory’s total of four R&D 100 Awards for 1998, significant contributions to the formation of a new $60M National Foundation for Functional Brain Imaging, and helping to formulate and launch a new national research initiative in structural genomics. Our scientific and technical activity lies in six major areas, which are discussed individually below.

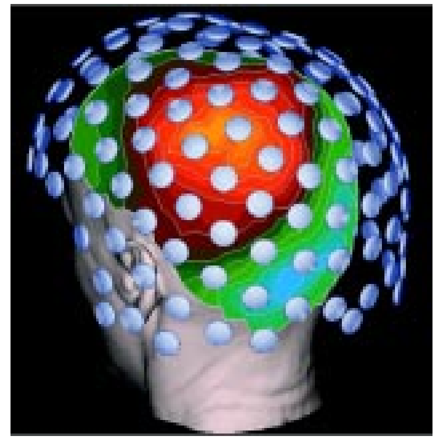


***Fig. 1** Our whole-head MEG system uses SQUID sensors to record the magnetic fields produced by active populations of neurons.*

Protein Structure, Dynamics, and Function

Our studies of protein dynamics aim to describe protein motion in atomic detail and understand the consequences of protein dynamics for protein function. We have extended our original work on kinetic x-ray crystallography of myoglobin[2] to the understanding of proteins important for bioremediation of trichloroethylene (TCE) and other soil and groundwater pollutants. P-21 is part of a multidisciplinary Los Alamos effort that seeks to enable bioremediation of TCE by genetically engineered microorganisms. The first step in this effort is obtaining a thorough understanding of the enzymatic mechanisms by which TCE can be degraded. In collaboration with scientists at universities across the country, as well as at the Max Planck Institute in Germany, P-21 scientists have begun to unravel the mystery surrounding the mechanism of one class of enzymes that might be engineered to degrade TCE: the cytochrome P-450s. P-450s bind molecular oxygen, split the dioxygen bond, and insert one oxygen atom into organic substrates. This can be the first step in the biodegradation of TCE. The reaction is also a crucial step in steroid hormone synthesis, and P450s are likely to be important in developing drugs to treat breast and other cancers.

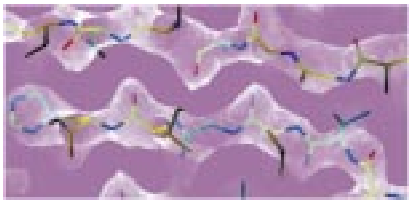


Fig. 2 An electron density contour map (pink) of an atomic model of that density (colored sticks). Solutions for protein structures such as this will be the primary emphasis of the protein crystallography program at the X8-C beamline.

To support our rapidly increasing efforts in protein crystallography, P-21 has converted beamline X8-C at the Brookhaven's NSLS to dedicated use for x-ray crystallography of proteins. Built originally for the Physics Division's weapons physics applications, the transition plan for this beamline was initiated in 1996 and completed in early 1998. To support this dedicated facility, we established an NSLS Participating Research Team consisting of the Los Alamos Integrated Structural Biology Resource, the National Research Council of Canada Biotechnology Research Institute, the Department of Energy (DOE) Molecular Biology Institute at the University of California at Los Angeles, the Brookhaven Biology Department, and the Pharmaceutical Division of Hoffman-La Roche, Inc. The primary emphasis at X8-C will be on solving novel protein structures through use of multiwavelength anomalous dispersion (MAD) on small crystals (100 µm and less) under cryogenic conditions (Fig. 2). X8-C is well-suited for this type of experiment because it has optics that deliver a high flux with low bandwidth when compared with other protein-crystallography beam lines at the NSLS.

Over the last year, the structural genome initiative (a systematic approach to obtaining the structures of large numbers of biologically and medically important proteins) has lead to the beginnings of a large-scale national effort with support from the DOE Office of Biological and Environmental Research and the National Institute of Health (NIH). Our goal is to maintain leadership in this area, which we expect to be both an important scientific issue in structural biology and a critical component of future biotechnology (there is already significant interest by major pharmaceutical companies). We were co-organizers of a national workshop entitled "Structural Genomics" which was held at Argonne National Laboratory in January 1998. The meeting was attended by internationally prominent figures in structural biology and genomics, as well as by representatives from the offices of DOE, NIH, the National Science Foundation, and other sponsors. The workshop produced an enthusiastic consensus that structural genomics will be an important part of the post-genome biological landscape. The meeting was widely reported in the scientific press.[3,4] In collaboration with members of the Life Sciences Division and the UCLA Molecular Biology Institute, we have begun a pilot project in structural genomics including large-scale overexpression, purification, and crystallization of proteins from a thermophilic bacterium. This project is expected to produce approximately 60 novel structures over the next three years, almost all of which will be solved by MAD techniques on beamline X8-C.

Functional Brain Imaging

A recent unpublished NIH position paper states "Brain imaging is one of the most rapidly advancing fields in science today. More than any other area of biology, it is a field in which the progress of research is dependent on improving technologies and computational power. . . [R]apid improvements in brain imaging methods provide our best hope for understanding brain mechanisms that play a role in mental illness and, eventually, for improving our ability to diagnose, treat, and prevent neurologically based brain disorders." P-21's effort in functional brain imaging focuses on the combined use of magnetoencephalography (MEG), anatomical MRI, functional magnetic resonance imaging (fMRI), and optical imaging techniques to develop improved techniques for noninvasive imaging of the human brain. High-resolution MEG arrays and optical imaging techniques are also used to image neural activity directly from the brains of experimental animals (Fig. 3). Together with collaborators at the University of New Mexico School of Medicine, Albuquerque Regional Federal Medical Center in New Mexico, Massachusetts General Hospital in Boston, and the University of Minnesota School of Medicine in Minneapolis, P-21's work in functional brain imaging contributed significantly to the recent formation of the $60M National Foundation for Functional Brain Imaging to be headquartered in Albuquerque.

Members of P-21 are engaged in projects to design improved multichannel magnetic sensors, develop more accurate mathematical models for localizing the electrical and magnetic signals from the brain, validate MEG using known current sources in computational and physical models of the brain, and use MEG to address important questions in basic neuroscience and in research on neurological and psychiatric disorders.

Combining MEG and anatomical MRI with other functional imaging techniques such as fMRI and positron emission tomography (PET) offers the opportunity of increasing the combined spatial and temporal resolution of functional imaging techniques well beyond that of any single method, as noted in the

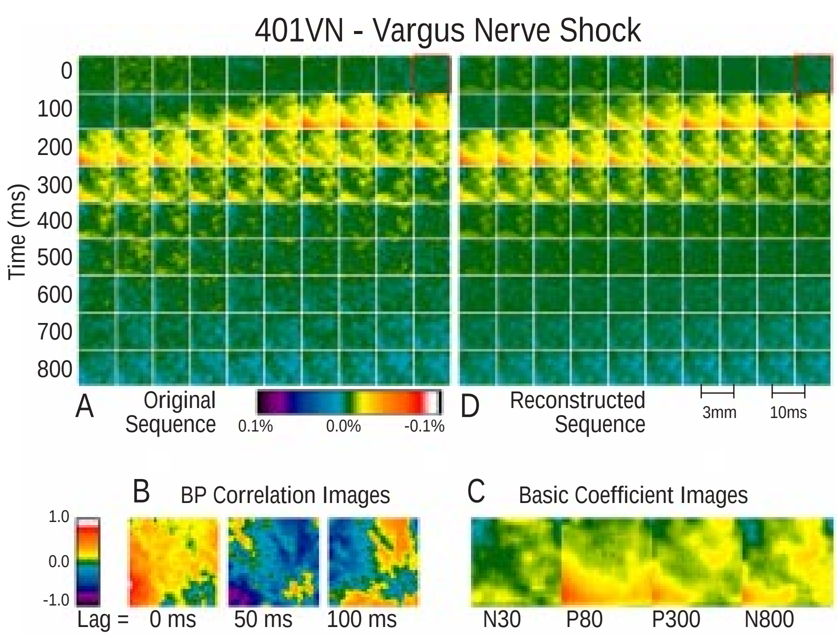


Fig. 3 High-resolution optical imaging techniques allow for images such as this, which accurately measure neural activity directly from the brain.

NIH quotation above. We are engaged in developing mathematical models for combining these alternative forms of brain imaging. This work is part of a nationwide effort to develop three-dimensional (3-D) computational models of the brain in which a variety of structural and functional information can be represented for storage, retrieval, and analysis.

SQUID-Based Sensors and Applications

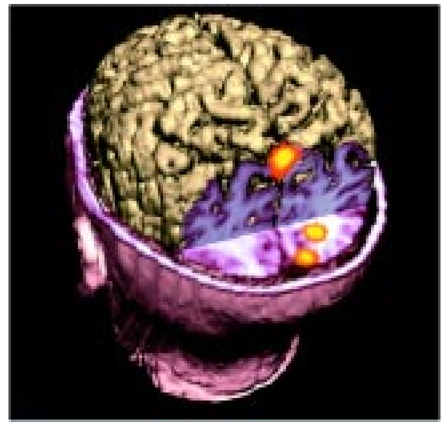
The goals of our MEG SQUID sensor projects are to develop, test, and evaluate sensor systems, numerical techniques, and computational models for functional imaging of the human brain using MEG. MEG involves the use of SQUIDs to measure magnetic fields associated with human-brain activity. Measurement of the magnetic fields of the brain (which are approximately a billion times smaller than Earth's) requires sensitive magnetic sensors, magnetic shielding from the environment (currently implemented through a shielded room), and advanced signal-enhancement and modeling techniques. Because magnetic fields readily penetrate the skull, MEG offers the potential for noninvasive measurement of brain function in much the same way that computed tomography and MRI allow the noninvasive detection of brain structure. MEG has therefore generated considerable interest in its possible use as a tool in basic neuroscience for functional mapping of the human brain, as a clinical tool for the assessment of neurological and psychiatric disorders, as a possible source of signals for use in the development of neural prosthetics and human-machine interfaces, and in other applied contexts.

MEG directly measures a physical effect of neuronal currents with temporal resolution not limited by the sluggish vascular response, unlike PET and fMRI that measure hemodynamic changes associated with neuronal activity. High temporal resolution is particularly important for studying neurological disorders such as epilepsy, where temporal information is a major diagnostic, and for fundamental studies of synchronization and oscillatory brain activity. Our whole-head MEG system is based on the P-21 patented principle of superconducting image-surface gradiometry where magnetic sources are imaged on the surface and magnetometers near the surface sense the combined fields as if the sensors were gradiometers (Fig. 4). Fabrication and assembly of this system are nearly complete. This system will play a major role in the National Foundation for Functional Brain Imaging.

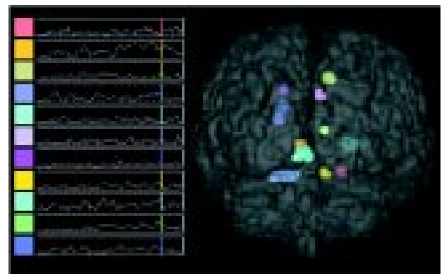
Significant progress has also been made in development of novel, improved approaches to the MEG forward and inverse problems. In the case of the forward problem, the two major existing approaches are spherical (or spherical-shell) models and boundary-element models. Spherical models have the advantage of computational simplicity but they can result in significant inaccuracies in regions of the head that depart from spherical geometry. In contrast, boundary-element models are more accurate, but at a significant increase in computational complexity. Working with our collaborators, we have developed an alternative to the spherical and boundary-element approaches to the forward problem, termed the weighted multi-sphere approach because it uses multiple spheres fit to the local curvature of the skull. This approach can achieve accuracies approaching those of the boundary-element model with computation time comparable to that of the simple spherical model. With respect to the inverse problem, members of P-21 recently demonstrated a new probabilistic approach based on Bayesian inference, which is described in detail in a research highlight in Chapter 2 of this report. Unlike all other approaches to the inverse problem, this approach does not result in a single “best” solution to the problem. Rather, it estimates a probability distribution of solutions upon which all subsequent inferences are based. This distribution provides a means of identifying and estimating the features of current sources from surface measurements that are most probable among the multiple solutions and can account for any set of surface MEG measurements. The promise of this approach has been demonstrated using computer simulations and experimental data. In particular, we have demonstrated for the first time that information can be extracted not only about the locations of regions of activity but also their extent.

In addition to applications of SQUIDs to MEG and related biological applications, members of P-21 have made significant accomplishments in applying these same sensors to the nondestructive evaluation of nuclear weapons components and materials. As described in detail in a research highlight in Chapter 2 of this report, a SQUID microscope has been designed, built, and tested for applications in the Enhanced Surveillance Program. This system uses a SQUID cooled by liquid nitrogen to map magnetic fields produced by eddy currents in a sample at room temperature. Material defects in the sample (due, for example, to cracks, seams, stress fractures, corrosion, or separation of layers) perturb eddy currents and produce magnetic field anomalies when compared to uniform, defect-free materials. Such anomalies can be detected even if the material defects are located below the surface in deeper layers of the sample. This latter capability is particularly important for nondestructive evaluation of weapons components and materials.

In the first full year of the project, the SQUID microscope team designed, fabricated, and performed successful initial tests of a SQUID microscope based on high-critical-temperature SQUID sensors. This work won P-21’s SQUID Microscope Team a Los Alamos Distinguished Performance Award for 1998. Their success was based in part on their ability to exploit P-21’s extensive experience in applications of SQUID sensors for noninvasive measurement of human brain function. Given this successful proof of concept, the team is now refining the SQUID microscope design to improve its sensitivity and resolution, to permit operation in magnetically noisy environments, and to use higher-frequency induction fields.



a)



b)

Fig. 4 In our whole head MEG system (shown in Fig. 1), the locations and time courses of active neural populations are calculated using computer models (a) and displayed on MRI images of brain anatomy (b).

Biologically Inspired Hardware, Computation, and Robotics

P-21 is currently making a significant effort in the study of adaptive systems focused on the development of autonomous or semi-autonomous machines, and there is an opportunity for this effort to become much larger. One focus of this work is the performance of simple mobile machines designed primarily to survive in their intended environment. Such devices are controlled by unique analog neural circuits, are often solar powered, and are capable of surprisingly complex behavior, and they may achieve enhanced utility through collective behavior. A second focus concerns the development of more capable robot legs modeled on the legs of insects. The aim is to develop legs that closely integrate the materials, sensors, actuators, power systems, and control structures as much as possible in the way that these components are integrated in the structure of animals. This work is the first step in the development of complex, agile walking robots. It is multi-disciplinary by nature, requiring the participation of materials scientists (for structure, energy systems, and actuators), mechanical and electrical engineers, bioscientists, physicists, and others. Opportunities exist for P-21 to become a major Laboratory and national resource in adaptive hardware, computation, and robotics for national security missions of the DOE Office of Nonproliferation and National Security, the intelligence community, and the Department of Defense (DOD) Advanced Research Projects Agency (DARPA). An expanded effort in this direction would exploit our existing strengths in robotics, engineering, neuroscience, and computation, and would significantly expand our contribution to core Laboratory missions with first-rate science and technology.

A major focus of such an expanded effort will be adaptive and biologically-inspired computation. Millions of years of evolution have endowed organisms with the ability to solve problems that overwhelm even the largest of today's DOE Defense Program stockpile stewardship computers. Biological solutions to these seemingly intractable computational problems involve massively parallel, richly interconnected networks of neurons whose collective activity is essential to their function. Artificial neural networks (ANNs), cellular automata, and other approaches to adaptive computation have achieved considerable notoriety as potential solutions to difficult computational problems because of their similarities to biological neural networks and because, unlike conventional numerical simulations, they do not require a detailed algorithmic solution to the problem a priori. Instead, because of their inherent plasticity and their ability to "learn" from experience, ANNs can be "trained" to solve problems in ways that are not explicit in their initial architecture.

ANNs are ultimately limited, however, because of their inherently rudimentary representation of the computational capabilities of real neurons. In actual neurons, tree-like dendritic structures are the site of a complex analog computation involving the timing of input spikes, the rapid interplay of voltage- and ion-specific membrane channels, and the active feedback of signals from the cell body back into the dendritic tree.[5] The size of ANNs to date is generally very small on the biological scale, where even the simplest of organisms have networks of hundreds of neurons, and most have vastly more. We believe that it is possible and desirable to begin to design neural networks that are more closely linked to biological neural systems, to use them to address hitherto intractable computational problems that biology appears to have solved in an elegant fashion, and ultimately to use systems of such realistic neurons to build useful devices.

Single Molecule Spectroscopy and Electrophoresis

P-21 and its collaborators have extended their work on the detection and characterization of single molecules in a liquid. The goal of this research is to measure and characterize the spectroscopic properties of individual molecules (Fig. 5). Such spectroscopic measurements can be used to identify the presence of a particular molecular species in an extremely dilute solution, or they can be used to probe the local environment that surrounds an individual molecule. The former capability promises a new level of speed and sensitivity for medical diagnostics, whereas the latter capability makes it possible to study properties of biological systems that cannot be measured when a lack of sensitivity confines measurements to the determination of the average properties of a large ensemble of microenvironments. Thus far, the spectroscopic properties measured at the single-molecule level include emission spectra, fluorescence lifetime, and total emission intensity. Recently the single-molecule spectroscopic approach has been extended to include single-molecule electrophoresis and approaches to ultrasensitive detection of viral and bacterial pathogens in soil and water samples. We are exploring additional applications for basic research and for medical diagnostics.

High-Speed Electronics Team

Already a diverse group, P-21 became more diverse and significantly stronger with the addition in December 1997 of the electronics team formerly in P-22. Previously a key element of the nuclear test program at the Nevada Test Site (NTS), the electronics team refocused its efforts to other defense and civilian needs with the cessation of nuclear testing. We now, quite literally, have the capability within P-21 to take an idea from the “gleam-in-the-eye” stage, through basic and applied research, to a fully developed, fieldable instrument for direct use by sponsors or industrial partners. The electronics team brings substantial capabilities in electronics design, fabrication, and implementation to P-21 that are of great value in their own right and have significant potential for the enhancement of our biological programs. In less than one year, the electronics team has made contributions in all of the focus areas listed above, including exploration of detectors derived from remote

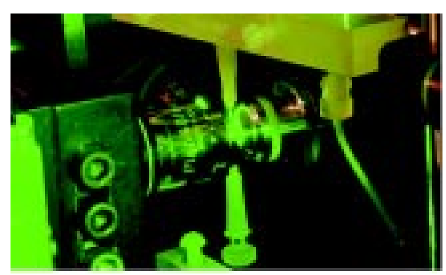


***Fig. 5** The single-molecule electrophoretic analyzer detects single labeled molecules in solution.*

ultra-low light imaging (RULLI) techniques (see the research highlight on this topic in Chapter 2) for applications in biomedical imaging and single molecule detection, contributions to high-throughput protein purification for the structural genome project, and other areas.

In collaboration with the Life Sciences Cytometry Group (LS-5), the P-21 Electronics Team played a key role in the development of a flow cytometer to be used as part of a suite of instruments by the U.S. Army Chemical and Biological Defense Command. The instrument provides point detection of a biological warfare attack at a forward battlefield location, and rapid identification of the biological warfare agent. The requirements called for the instrument to be exceptionally compact, rugged, and easy to use while precisely identifying a host of bio-agents. The miniature flow cytometer (MiniFCM) successfully completed field tests in September 1998, and 14 instruments are currently in use at Fort Polk, Louisiana.

The electronics team significantly increased the dynamic range of the instrument while also reducing the size of the required electronics (Fig. 6). A unique scheme of data acquisition, which used two ADC's and overlapped their coverage, was used to increase the dynamic range to 16 bits with very low noise. Simultaneously detecting particles in very low channels and high channels was fundamental to the use of the instrument (Fig. 7). In addition, the size of the MiniFCM was reduced by designing acquisition electronics around a multichip module hybrid, which placed 32 integrated circuits on a 30 × 55-mm substrate. The team also simplified the controls and user interface of the instrument, transforming a clinical instrument controlled by a separate PC and software into a field instrument controlled by five buttons.

***Fig. 6** The miniFCM can detect specific bio-aerosols, cells, and spores within 120 seconds. It is self-contained and easily portable, weighing only 60 lbs and measuring 2.5 ft³.*

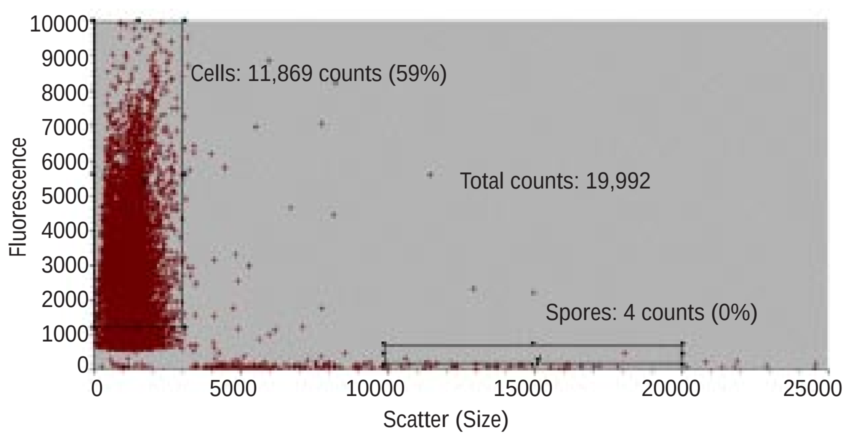


***Fig. 7** Bivariate dot plot of size (scatter) versus DNA fluorescence for particles detected during a field trial of the miniFCM at Dugway Proving Ground.* Erwinia herbicola*, a vegetative cell that causes black spots on pears, was released outdoors. The miniFCM was able to detect both the cells (upper left) and spores (lower right) of this pathogen simultaneously, even though the spores are larger and less fluorescent.*

The instrument is part of a mobile bio-agent laboratory. It consists of a precisely aligned and focused optical platform, a fluidic system for sample delivery and system decontamination, and a virtual memory extension (VME)-based data acquisition and control system. Unlike commercial flow cytometers, these systems had to be made physically rugged to survive transportation and be immediately on-line for bio-agent detection. This required extremely stabile optical and fluidic components and special detail in every aspect of instrument construction. The result is a remarkably high level of adjustment-free operation, especially when compared to standard commercial instruments.

Further Information

For further information on all of P-21's projects, refer to the project descriptions in Chapter 3 of this progress report. Some of our major achievements are also covered as research highlights in Chapter 2, as mentioned above. These include SQUID microscope development, research on Bayesian methods for addressing the MEG inverse problem, development of RULLI techniques, and the structural genome project.

References

[1] D. A. Doyle, J. M. Cabral, R. A. Pfuetzner, A. Kuo, J. M. Gulbis, S. L. Cohen, T. Chait, and R. MacKinnon, "The Structure of the Potassium Channel: Molecular Basis of K^+ Conduction and Selectivity," *Science* 280, 69 (1998).

[2] I. Schlichting, J. Berendzen, G. N. Phillips, and R. M. Sweet, "Crystal Structure of Photolyzed Carbonmonoxy-Myoglobin," *Nature* 371, 808 (1994).

[3] E. Pennisi, "Taking a Structured Approach to Understanding Proteins," *Science* 279, 978 (1998).

[4] L. Shapiro and C. D. Lima, "The Argonne Structural Genomics Workshop: Lamaze Class for the Birth of a New Field," *Structure* 6, 265, (1998).

[5] T. J. Sejnowski, "The Year of the Dendrite," *Science* 275, 178 (1997).

P-22: Hydrodynamic and X-Ray Physics

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Jack Shlachter,
Deputy Group Leader

Introduction

The mission of the Hydrodynamics and X-Ray Physics Group (P-22) is to solve challenging experimental physics problems relevant to our national security, aiming to reduce the threat of war by helping to ensure the reliability of our nuclear-weapons stockpile and by limiting the proliferation of weapons of mass destruction. Our experiments focus on the hydrodynamic properties of materials as they undergo explosive and implosive forces. For nuclear weapons and other highly dynamic systems, knowledge of material behavior under extreme physical conditions is important for developing computational models. Our x-ray capability is predominantly involved in the diagnosis of dynamic material behavior.

To fulfill its mission, P-22 maintains and develops a creative multidisciplinary team, broad physics and engineering capabilities, and state-of-the-art technologies. Experimental efforts in P-22 cover a wide range of physics disciplines, including hydrodynamics, x-ray spectroscopy and imaging, plasma physics, radiation hydrodynamics, optics and fiber optics, microwaves, electromagnetics, atmospheric physics, and atomic physics. In support of these experiments, P-22 has expertise in a variety of engineering disciplines, including analog and digital electronics; electro-optics instrument design and fabrication; high-voltage, low-inductance pulsed-power engineering; and fast-transient data recording. P-22 is also the home of the Pegasus II Pulsed-Power Facility (Fig. 1) and of the future Atlas High-Energy Pulsed-Power Facility (Fig. 2). These high-energy experimental facilities provide a valuable laboratory test bed for the investigation of dynamic material properties.

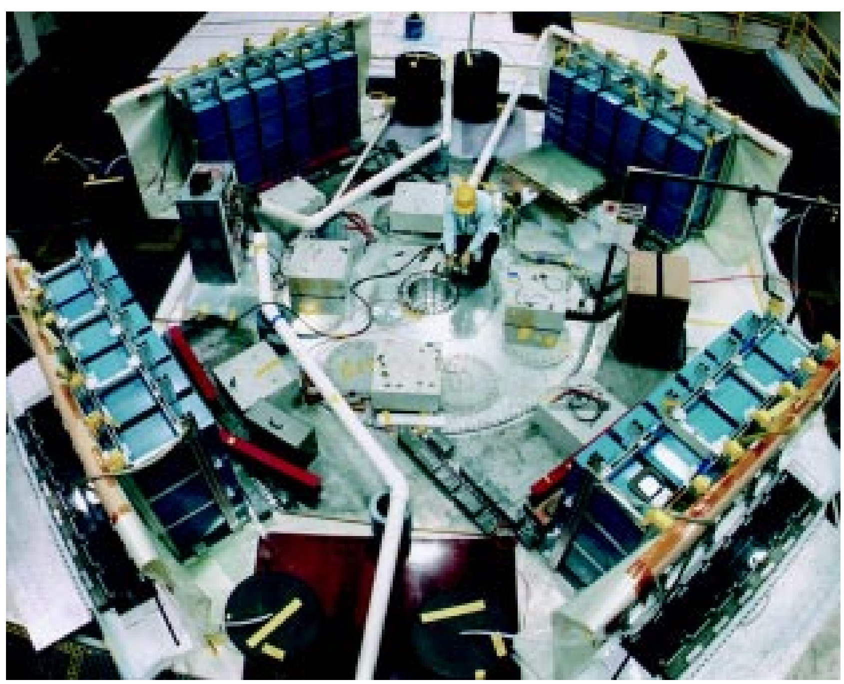


***Fig. 1** View of the upper half of Pegasus II. The facility consists of 144 energy-storage capacitors arranged as a two-stage Marx bank with a maximum erect voltage of 100 kV.*

Fig. 2 The Atlas capacitor bank will be housed in 12 oil tanks that are arranged around a centrally located target chamber. Each oil tank will contain up to two removable maintenance units and up to 32 capacitors.

The mainstay of P-22 has traditionally been its support of the nuclear-weapons program. P-22 continues this tradition by supporting science-based stockpile stewardship (SBSS), which is the foundation of the present Los Alamos nuclear-weapons program. SBSS requires the development of complex experiments on diverse facilities to address the relevant physics issues of the enduring stockpile. In P-22, we support SBSS by applying the scientific and engineering expertise that we developed for the nuclear test program to investigate and understand primary and secondary weapons-physics issues that are crucial in a world without nuclear testing.

Nevada Test Site

P-22 is deeply involved in protecting and archiving the volatile test data it took during more than three decades of underground nuclear testing at the Nevada Test Site (NTS). Our goal is to bring the group's data to a stable and readily accessible state. These data will be used to benchmark all future calculational tools. The archiving activities constitute a significant effort in P-22 and involve individuals responsible for the original execution of underground nuclear tests as well as trainees. Many of the numerical algorithms developed for analyzing the information from underground tests have been ported to modern computer platforms as part of our effort to preserve this valuable and unique data.

In addition, P-22 continues to participate in experiments performed underground at NTS, both to maintain our readiness to support a resumption of nuclear testing should the need arise, and to study the physics of weapons performance and materials (Fig. 3). These experiments increase our understanding of weapons science by allowing improvements in code calculations and in estimates of the severity of problems and changes occurring in the nuclear stockpile as it ages.

Fig. 3 P-22 data recording trailer at the NTS U1A underground test facility. The trailer uses modern fiber-optic systems and state-of-the-art digitizers and timing systems to gather and record data from explosive experiments located almost 1,000 ft below ground.

At present, we are supporting the Los Alamos Dynamic Experimentation (DX) Division on experiments to measure the properties of material ejected from shocked plutonium. These experimental efforts are discussed in detail in a research highlight in Chapter 2. By performing these experiments underground at NTS, the plutonium is handled and contained in a manner similar to that used for underground nuclear tests, maintaining the readiness training necessary to support the potential for future nuclear tests.

Above-Ground Experiments

In support of the Weapons Program's above-ground experiments (AGEX-1), we have been developing diagnostics to study the physics of high-pressure shock waves. Among the diagnostics currently under development are

- visible-wavelength and infrared pyrometers to determine the temperature history of the back surface of a shocked material under conditions where this surface either releases into free space or is tamped by an anvil,
- low-energy x-ray sources for imaging of shock-produced low-density material (ejecta), and
- a technique for measuring the speed at which moving, high-density material can produce a fiber-optic signal.

We anticipate development of several other techniques to study material phases, including

- a very-short-pulsed laser and an ultrafast streak camera to determine by either second harmonic generation or reflectivity whether the surface of a shocked sample has melted, and
- an x-ray diffraction technique to measure phase changes at the surface of a shocked sample.

These diagnostics will be used to study shocks produced by explosives, flyer plates, gas guns, and the Pegasus capacitor bank.

In other AGEX-1 work, we are supporting the development of the Dual-Axis Radiographic Hydrotest Facility (DARHT) by studying the beam physics of DARHT's prototype, the Integrated Test Stand (ITS). We have built and successfully fielded a magnetic spectrometer to measure the beam energy as a function of time in the 70-ns ITS pulse. In addition, we are developing a microwave interferometry diagnostic to nonintrusively measure the beam electron density and properties of the expanding target plasma created in the interaction of the electron beam and bremsstrahlung converter. We are also participating in the development of new nonintrusive beam diagnostics for the 2-μs injector of the DARHT second axis.

High Energy Density Physics

The High Energy Density Physics (HEDP) program has been conducting experiments of interest to the weapons community at the 4.6-MJ Pegasus II Pulsed-Power Facility, which can be used as a radiation driver or as a hydrodynamic driver in convergent geometry (Fig. 4). Experiments are being performed to investigate a wide range of phenomena, including nonsymmetrical hydrodynamic flow, the behavior of materials undergoing large strains at high strain-rates, frictional forces at interfaces with differential velocities on the order of kilometers per second, instability growth at interfaces in materials with and without material strength, and ejecta formation of shocked surfaces. In addition, we are pursuing pulsed-power research on liner stability, current joints, and power-flow channels to ensure optimal performance for the future Atlas facility and for advanced, high-current, explosive pulsed-power systems. P-22 has already provided pulsed-power and diagnostic expertise to Procyon, Ranchito, and Ranchero, the Laboratory's existing high-explosive pulsed-power systems.

P-22 is the future home of Atlas, the next-generation 23-MJ pulsed-power facility. Atlas will provide advanced equation-of-state (EOS), material property, and hydrodynamic capabilities for weapons-physics and basic research. 1996 marked the official start of the Atlas construction project, with the first dollars arriving for detailed facility design. A major milestone in the project, approval of the DOE critical decision (CD-3) that authorized the start of construction, was reached during 1998. Research and development (R&D) activities since 1996 have been centered on component development, prototype design and testing, and preliminary design of Atlas experiments that will provide an understanding of the scaling of physical phenomena from present data to higher energies. Physics issues of interest are material properties at high strains and strain rates, EOS measurements at high pressures, hydrodynamic response and EOS of strongly coupled plasmas, and interface physics. The Pegasus and Atlas facilities and the current and anticipated research activities are described in detail in a research highlight in Chapter 2 of this progress report.

In another part of the HEDP program, P-22's plasma-physics expertise and ability to do large-scale integrated experiments have provided group members with the opportunity to participate in several collaborations with the premier All-Russian Institute of Experimental Physics at Arzamas-16 (VNIIEF), the weapons-design laboratory that is the Russian counterpart to Los Alamos. In addition to giving us the chance to learn about some of the Russians' unique capabilities, the collaborations provide Russian weapons designers with an opportunity to do peaceful basic scientific research and to integrate themselves into the world's broader scientific community. These collaborations are based on our mutual interests in high-explosive-driven pulsed power, wherein the Russians have clearly demonstrated scalability to large systems that is unmatched to date in the United States. P-22 is

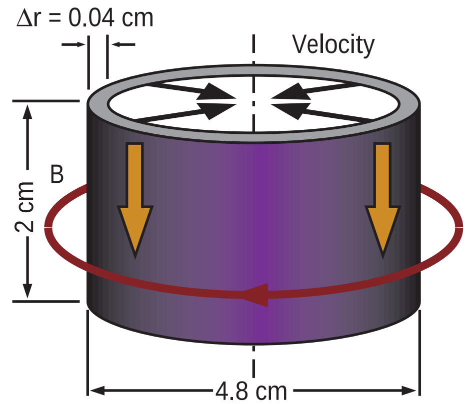


***Fig. 4** Recent research at Pegasus II has focused on hydrodynamic experiments using a standardized solid, cylindrical drive liner. Pulsed electrical currents create a strong magnetic field (B) and high current density around the liner. The interaction of the current and magnetic field produces forces that implode the liner.*

participating in several major collaborative efforts, including experiments on the Russian MAGO system, a possible candidate for magnetized target fusion; attempts to convert a frozen rare gas to a metal by compressing it in a large magnetic field; the design and testing of a thin, imploding cylinder for a megajoule x-ray source; and studies of the properties of materials at cryogenic temperatures in magnetic fields up to 1,000 T.

We are continuing to perform integrated and fundamental radiation hydrodynamic experiments using laser- and z-pinch-driven radiation sources at the Nova and Z facilities at Lawrence Livermore National Laboratory and Sandia National Laboratory, respectively (Fig. 5). We have developed diagnostics for measuring radiation flow, including x-radiography, VISAR, gated x-ray imagers, filtered x-ray diodes, a curved-crystal spectrometer for stimulated fluorescence spectroscopy, and both active and passive shock breakout techniques. Our investigations have examined integrated experiments to understand radiation flow and to evaluate the usefulness of dynamic hohlraum radiation sources for a variety of future applications.

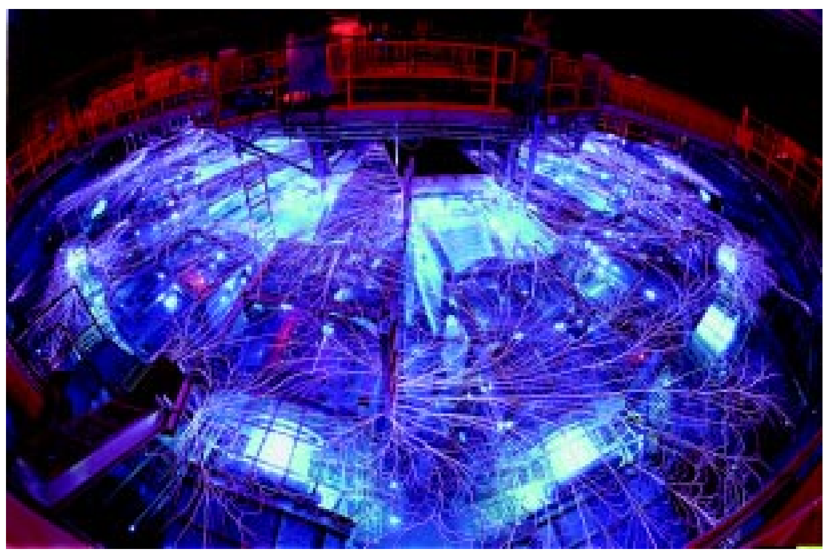


***Fig. 5** The Z machine photographed as it is firing. Recent radiation experiments on the Z machine have set records for machine performance and provided a basis for weapons physics experiments in support of science-based stockpile stewardship.*

Future Directions

We anticipate a lot of exciting developments in the coming years. As the future operators of the Atlas facility, scheduled to come on-line in 2001, we will continue to support facility development and prepare for future research by testing our experimental designs and calculations at Pegasus and other facilities. In addition, we will focus on diagnostic development to support upcoming experiments at NTS and other AGEX-1 facilities. For further information on all of P-22's projects, refer to the project descriptions in Chapter 3. Some of our major achievements are also covered as research highlights in Chapter 2. These include experiments at the Pegasus facility and development of the Atlas facility, as well as our recent experimental collaborations at NTS.

P-23: Neutron Science and Technology

Mary Hockaday,
Group Leader

Susan Seestrom,
Deputy Group Leader

Introduction

The Neutron Science and Technology Group (P-23) carries out a synergistic program of basic and applied research in weapons physics, nuclear physics, and quantum information science. The common feature of this diverse set of efforts is the application of state-of-the-art techniques in particle and light detection and the recording of transient events.

Within the area of weapons physics, we participate in design and fielding of subcritical experiments, non-nuclear hydrodynamic experiments in support of above-ground experiments (AGEX-I), pulsed-power experiments, and archiving and analyzing data from past nuclear-weapons tests. Our fundamental research focuses on nuclear and weak-interaction physics and on astrophysical phenomena involving the detection of solar neutrinos and ultra-high-energy gamma rays. Applied research includes the development of quantum-information technologies, such as quantum computation and encryption (involving single-photon detection) and the application of imaging and neutron technologies to problems relevant to national defense or industry.

We conduct our research at local facilities such as the Los Alamos Neutron Scattering Center (LANSCE), Pegasus, Milagro (Fig. 1), and local firing sites, as well as at remote facilities like the Nevada Test Site (NTS) and the Sudbury Neutrino Observatory (SNO). All of these facilities are world class, offering the best available resources for our research. Of these facilities, only the Milagro

***Fig. 1** The Milagro detector is comprised of 723 photomultiplier tubes situated in a 5,000-m^2, 8-m-deep pond at an altitude of 8,700 ft. The photograph shows the pond before it has been filled with water, which will allow the Kevlar-bound photomultiplier tubes to extend towards the sky. Milagro should be able to detect the particle showers produced by very high-energy gamma rays as they enter the atmosphere.*

gamma ray observatory is owned and operated by P-23. We contribute to Laboratory programs in science-based stockpile stewardship (SBSS), accelerator production of tritium (APT), and energy research, as described below.

Weapons Physics and Science-Based Stockpile Stewardship

With the end of nuclear testing, SBSS has become the foundation of the Los Alamos nuclear-weapons program. Our knowledge of how complete nuclear weapon systems perform relies on data obtained from tests at NTS and test locations in the Pacific Ocean. Saving, analyzing, and documenting NTS weapons test data is crucial to the success of SBSS. P-23 shares responsibility for preservation and analysis of these data with other groups involved in these tests. In P-23, physicists and engineers who performed the original measurements are working to analyze and correlate the data of different events. In addition, new scientists are learning the technologies of making such measurements in case the need should arise for future underground tests.

The work of the group concentrates on analysis of pinhole neutron experiments (PINEX) imaging data and on neutron emission measurements (NUEX and THREX). These data complement the reaction history and radiochemical measurements made by other groups. As a whole, this research has provided a better understanding of the underlying physical processes that generated the data, and the comparison of results from different tests has allowed us to study systematically the behavior of nuclear explosives.

To ensure the success of SBSS in allowing us to certify the performance of our nuclear weapons in the absence of nuclear testing, P-23 is striving to develop better physics models that can be incorporated into computer codes to calculate explosive performance. Only by validating such codes with the existing NTS data will we be able to address with confidence the issues of aging and remanufacture of our stockpile weapons.

In addition to the analysis of NTS data, P-23 is participating in a series of experiments to explore weapons-physics issues of a more microscopic nature. In these experiments, we use chemical explosives and pulsed-power machines such as Pegasus to examine issues such as the EOS of shocked materials, formation and transport of ejecta from shocked surfaces, and growth of hydrodynamic instabilities. Our work includes a series of underground experiments involving plutonium at the U1a facility at NTS. These experiments employ a wide range of technologies, including gated visible imaging, gated x-ray imaging, holography, and infrared temperature measurement, to explore the physical phenomena. P-23 is currently developing fast infrared imaging technology, which will provide the ability to study freeze-frame dynamic motion in the infrared range. The data from all of these technologies allow us to better understand hydrodynamics of interest to the weapons program. As computer models are developed further, the data will allow us to benchmark the models.

Other weapons program work focuses on what happens to a weapon as its components age. NTS experiments and other previous weapons tests did not focus on this issue, and the data from these tests are not sufficient to assure the safety and reliability of the nuclear-weapons stockpile without nuclear testing. The SBSS program is intended to provide a scientific basis for addressing this and other assurance issues without nuclear testing. As part of this effort we have joined colleagues in other groups and divisions at Los Alamos National Laboratory, as well as from the Lawrence Livermore National Laboratory, to study the following issues:

- the performance of chemical explosives, including changes in performance as they age;
- the fundamental physics of plutonium, *e.g.*, the phonon spectrum;
- the temperature of materials undergoing hydrodynamic instabilities; and
- nuclear cross sections that are required for better analysis of radiochemical data from previous weapons tests.

For these studies we use neutrons from LANSCE sources, including moderated neutrons from the Manual Lujan, Jr., Neutron Scattering Center (MLNSC), moderated neutrons with tailored time-structure from the Weapons Neutron Research (WNR) Blue Room, and unmoderated neutrons from the WNR fast-neutron source. Neutron spectroscopy by time-of-flight techniques is central to all of these projects.

An important element of the SBSS program at LANSCE is hadron radiography. P-23 is supporting this effort with a cold-neutron radiography project at the MLNSC and by participation in the proton-radiography project. P-23 developed a cooled, charge-coupled device (CCD) imaging system with fast gating and image intensification for use in hadron radiography. The system was first applied to radiograph a low-density material encapsulated in a high-density casing using neutrons produced at the WNR in the 5- to 200-MeV energy range. The group has also collaborated with the Subatomic Physics Group (P-25) in the development of a pixellated, gas-amplification wire-chamber detector for hadron radiography. Our future work includes development of framing camera techniques to be applied to proton radiography. We propose to include a framing camera between the image intensifier and the CCD camera. This will enable the recording of four frames on each CCD and would increase the total number of frames to 28.

P-23 also supports the SBSS program by obtaining nuclear data at the WNR facility. At WNR, a large array of Compton-suppressed germanium detectors, known collectively as the GEANIE detector, is used to measure gamma rays from neutron-induced reactions. Our interests at present are in the ^{239}Pu(n,2n)^{238}Pu cross section, where different nuclear-reaction models give markedly different predictions, and in the nuclear structure area of "complete spectroscopy," where models of nuclear-structure symmetries and the transition from order to chaos in nuclear spectroscopy can be tested.

A critical, and currently limiting, component to a number of weapons program experiments is the need for better imaging technologies. Prior to the cessation of underground testing at NTS, the Laboratory (previously in J-12 and P-15, and then in P-23) developed an in-house capability to meet the advanced imaging needs for the Weapons Program's underground shots. Currently, the SBSS program has turned to above-ground experiments that are again placing ever increasing demands on imaging and other technologies. There is currently a need for an imaging sensor that can be gated (or shuttered) in the few-nanosecond to subnanosecond regime, can achieve a high frame (or data) transfer rate (up to 10^7 frames per second), has a high quantum efficiency (1% to 50%) and sensitivity (<10 photons per pixel detection), and covers the spectrum from visible light into the near-infrared regime (380 nm to 5 μm in wavelength). Such advanced imaging capability is not available commercially, and the technology for achieving such imaging is presently state-of-the-art or in development.

Accelerator Production of Tritium

P-23 contributes to the APT program by supplying basic nuclear-physics data, performing integral tests of the calculated neutronic performance of benchmark systems, developing beam diagnostics, and participating in irradiation studies of components for this program. Basic nuclear physics data include neutron total and reaction cross sections and activation data, mostly measured with the spallation neutron source at WNR. Integral tests employ small-scale mockups of the accelerator target and the neutron-reflecting blanket. These allow the initial neutron production, the final tritium production, and intermediate steps to be quantified and compared with calculations. Beam diagnostics use P-23's imaging capabilities. These data-measurement activities and integral demonstrations are continuing as the APT program progresses.

Nuclear Research

Compound nuclear states provide an excellent laboratory for studying violation of basic symmetries because of enhancements of the effect of parity violation in this system that are of order 10^7. The origin of these enhancements is a combination high-level

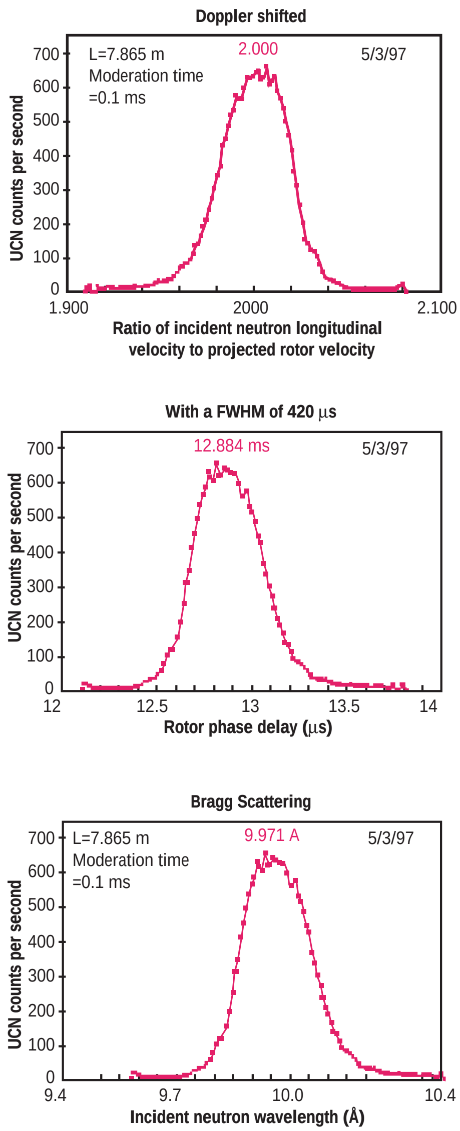


Fig. 2 Conditions and results for the UCN rotor reflector experiments. Thirty UCN per pulse were detected when the rotor was within 90 µs of the center. Slow neutrons generated with the rotor reflector system will be used to investigate the radioactive decay of free neutrons.

density and large difference between *s*-wave and *p*-wave neutron widths. This width difference enhances the effects of parity violation because we observe mixing of large *s*-wave resonances into small *p*-wave resonances. In the past we have observed parity violation in neutron resonance reactions for a large number of resonances in more than a dozen target isotopes. With techniques developed by P-23 and our partners, we identified very weak p-wave resonances where parity violation can occur and be observed with amplitudes of up to 10% of parity-conserving interactions. Nuclear theory predicted that the sign of the parity-violating effect should be random, and for all but one nucleus it appears to be. The exception is thorium-232 (^{232}Th), where the violation for the eight resonances with the strongest effects are all of the same sign, which would have a less than 0.25% probability of occurring if the sign were indeed random. We have investigated all of the readily available isotopes at maxima in the p-wave strength function and therefore are bringing this research to a close. The case of ^{232}Th remains an enigma. As a follow-on to our work in parity violation in heavy nuclei, we are developing an experiment to measure parity violation in the *np* system. This experiment will attempt to measure the asymmetry in gamma rays emitted after capture of polarized neutrons by protons in a liquid-hydrogen target. The experiment will be conducted at the MLNSC, and the shuttle, beam guides, and apparatus are currently in design.

We are also active in other tests of fundamental symmetries in the beta decay of trapped atoms and of free neutrons. Sensitive tests of the parity-violating beta-spin asymmetry correlation in the decay of rubidium-82 (^{82}Rb) constitute one experimental sequence that we anticipate will yield results with a precision one order of magnitude greater than any previous experiment (see the detailed research highlight on this topic in Chapter 2). In studies of the decay of the free neutron, we initiated the EMIT (“time” reversed) collaboration to pursue a search for time-reversal invariance violation. For this we have designed an experiment that promises to be seven times more sensitive than previous experiments. We have also proposed an experiment to measure the beta asymmetry in the beta decay of polarized ultracold neutrons (UCN).

UCN were first produced at LANSCE in 1996 by the use of a rotor reflector (Fig. 2). These neutrons travel with speeds of less than 8 m/s. We are continuing to develop this source with improved cold moderators and better rotor reflectors. We plan to use this source to test the key concepts in an experiment to measure the radioactive decay of free neutrons. We are also doing research and development aimed at an experiment to measure the neutron electric dipole moment using UCN produced and stored in a bath of superfluid ^{4}He. Both of these measurements aim at detecting physics beyond the standard model of strong and electroweak interactions. We are also studying the feasibility of a cryogenic source of UCN to be operated as a stand-alone spallation UCN source. Preliminary indications are that such a source, using only a few percent of the LANSCE proton beam, could provide the world’s most intense source of UCN. Such a world-class source of UCN at LANSCE would open up new opportunities for experiments in fundamental physics and the possibility of novel applications to materials science.

Another area in basic nuclear research is the Milagro project (see Fig. 1). Very high-energy gamma rays from the cosmos can be detected when they enter the atmosphere and produce an air shower of particles. The Milagro project, located in the Jemez Mountains above Los Alamos, involves the construction and operation of a high-efficiency observatory for gamma rays in the energy range around 10^{14} eV. This observatory is a joint project of Los Alamos and a large number of universities. It will be especially well-suited for the study of episodic or transient gamma-ray sources—that is, for recording gamma-ray bursts. It is operational 24 hours a day, 365 days a year, and its field of view is nearly half of the sky. A small scale version of Milagro, Milagrito, operated in 1998. The full-scale detector is presently being assembled.

We are also involved in ongoing research of solar neutrinos. The number and spectrum of neutrinos from the sun continues to challenge our understanding of solar physics and neutrino properties. For many years we have been working with scientists from the (former) Soviet Union to detect neutrinos by using large quantities of gallium far underground in the Caucasus Mountains. This lengthy study, known as the SAGE (Soviet-American Gallium Experiment) collaboration, has revealed that the number of neutrinos detected is about half of that predicted by the best solar and neutrino models. Now we are collaborating in the development of SNO, a neutrino observatory more than a mile underground in Sudbury, Ontario. The SNO detector will soon be operational and consists of an acrylic vessel holding 1,000 tonnes of heavy water surrounded by another vessel with 8,000 tonnes of light (regular) water. All three flavors of neutrinos (electron, muon, and tau) will be detected. Development of this detector includes the design and fabrication of very-low-background ^{3}He detectors and new electronics. As a spin-off, the very sensitive, low-background detectors developed for the observatory will be used to screen high-density microelectronics for trace radioactive contaminants that can cause computer errors by “flipping” bit patterns. The physical structure has been completed, and the vessel is being filled with water. The first ^{3}He detectors have been tested underground at Sudbury, and they perform as expected. We expect to complete construction and have all counters underground by summer 1999.

Applications of Basic Research

Quantum computation, a field in its infancy, promises a new approach to solving some problems (regarded as intractable in classical computation) by using the quantum-mechanical superposition of many states (numbers) at once. To realize such a computer, we are developing a system with cold, trapped atoms that represent the quantum-mechanical states. Quantum logical operations are performed with laser manipulations of the states of the trapped atoms (Fig. 3). Using conventional lasers, we have recently succeeded in trapping and imaging calcium ions that have the required spectroscopic structure to allow them to serve as basic quantum-mechanical bits. We are developing advanced diode lasers to perform the same operation, but with much reduced power requirements and cost.

Our applied research also includes work in quantum cryptography, which is covered in a detailed research highlight in Chapter 2. Quantum mechanics provides an approach to unbreakable cryptographic codes that not only can transmit the code "key" with security but that can also reveal the presence of eavesdropping. We have demonstrated this quantum cryptography over 48 km of fiber-optic cable and are developing longer transmission demonstrations. In a related effort, we have demonstrated transmission of a "key" through 200 m of air, and through this technology we are aiming at establishing secure communications between ground-based stations and low-Earth-orbit satellites.

We are also carrying out fundamental studies in "interaction-free measurements." Using the complementary wave- and particle-like nature of light, it is possible to determine the presence of an object without any photons being absorbed or scattered by it. Based on

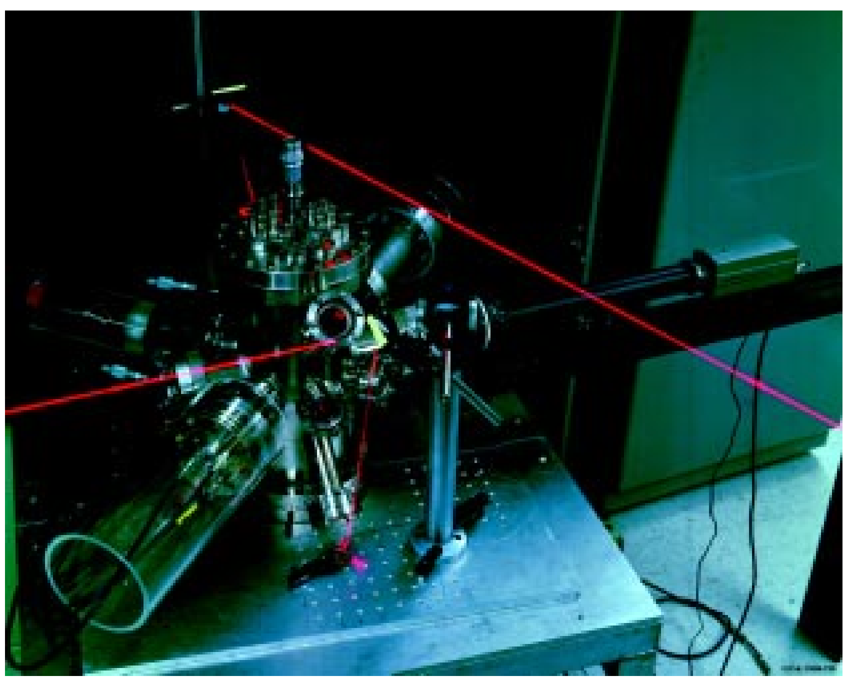


***Fig. 3** Apparatus for manipulating the states of cold, trapped atoms. Using such a system, we have succeeded in trapping and imaging calcium ions that have the required spectroscopic structure to allow them to serve as basic quantum-mechanical bits for quantum computation.*

these studies, we have begun investigating the practical implementation of “interaction-free imaging,” where the techniques are used to take a pixellated image of an object, again with the goal of negligible absorption or scattering; at present, a resolution of better than 10 μm has been achieved, and we hope to reduce this even further. This work is covered in a detailed research highlight in Chapter 2.

We also support DOD programs in mine detection and seeker applications. For the detection of land mines, we are investigating the use of neutrons as an interrogating probe, with the detection of the resulting activation gamma rays as the positive signature. High-intensity neutron sources are necessary for the required sensitivity, and we are developing them in collaboration with other groups. Accelerator sources are strongly preferred because their energy can be tuned and specified, and they can be turned off when not in use. We are assessing the required sensitivity of detection, using our extensive experience acquired in developing neutron detectors for the Nuclear Test Program and for accelerator-based experiments. P-23 has also developed a laser-based, range-gated imaging system for the airborne detection of submerged mines. The system has undergone testing in both controlled-tank and open-sea environments. We have supported seeker (target identification) programs with range-gated laser distancing and ranging (LADAR) experiments carried out at the Wright Laboratory’s laser range at Eglin Air Force Base. These experiments are part of a joint DOE/DOD technology-development program.

Further Information

To learn more about the projects described here, as well as other projects within P-23, refer to the project descriptions in Chapter 3. Some of our major achievements are also covered as research highlights in Chapter 2, as mentioned above. These include our work in quantum computation, interaction-free measurement, free-space quantum key distribution, and fundamental symmetries with magnetically trapped ^{82}Rb.

P-24: Plasma Physics

Kurt F. Schoenberg,
Group Leader

Juan C. Fernández,
Deputy Group Leader

Introduction

The Plasma Physics Group (P-24) researches the basic properties of plasmas with a view to applications in important Los Alamos National Laboratory and national programs. Plasmas occur in nature when matter exceeds temperatures of roughly 10,000°C. At these temperatures, the constituent atoms and molecules of matter begin to lose their bound electrons to form a substance composed of positive or negative ions and free electrons. All principal phenomena in plasmas can be traced to the fact that ions and electrons interact with each other through long-range electromagnetic forces. The electromagnetic interactions of groups of charged particles are often coherent, leading to collective modes of plasma behavior. This collective interaction of charged particles, a many-body problem, is the essence of the field of plasma physics.

Roughly 99% of the matter in the universe is in a plasma state. Plasmas can exist over a large range of temperatures and densities. For example, interstellar space contains plasmas with densities of less than one ion or electron per cubic meter at temperatures exceeding 1,000°C. In contrast, plasmas created by intense laser compression of micropellets achieve densities up to 10^{26} ions or electrons per cubic centimeter at temperatures exceeding 10,000,000°C. The understanding and application of such diverse plasmas is a Los Alamos core competency.

P-24 is composed of a diverse technical staff with expertise in plasma physics, plasma chemistry, atomic physics, and laser and optical science. The group uses both on-site and off-site experimental facilities to address problems of national significance in inertial and magnetic fusion, high-energy-density physics, conventional defense, environmental management, and plasma-based advanced or green manufacturing. Our agenda includes basic research in the properties of energetic matter and applied research that supports the principal Laboratory mission of reducing the nuclear danger. The pursuit of this agenda entails the physics of plasmas over a wide and diverse range of conditions, as shown in Fig. 1.

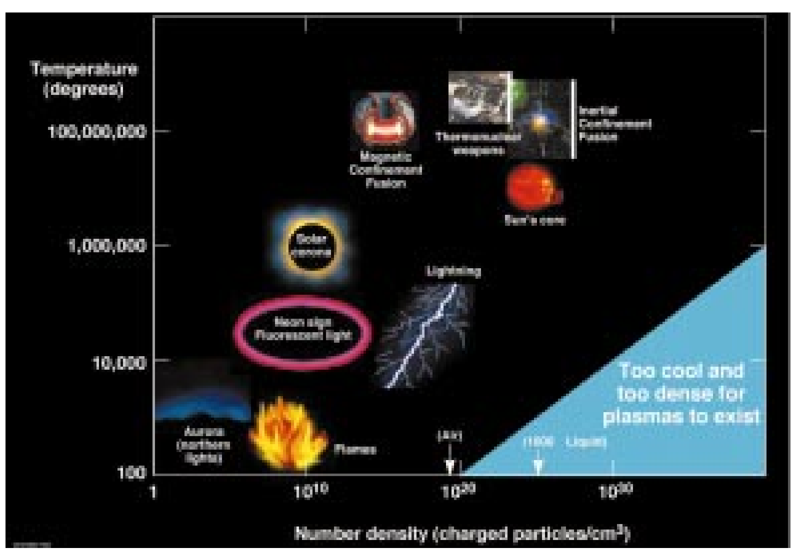


***Fig. 1** As this illustration of the plasma state shows, the physics of plasmas entails a wide and diverse range of conditions.* **(Illustration courtesy of Dr. Don Correll, Lawrence Livermore National Laboratory)**

Atlas

Atlas, a 24-MJ, 30-MA advanced pulsed-power facility scheduled for completion in late 2000, will be capable of imploding 40-g cylindrical liners at velocities of up to 20 km/s on timescales of several microseconds. Such implosions will produce material pressures of several tens of megabars, magnetic fields up to 1,000 T, material strain rates of 10^6 s^{-1}, and highly coupled plasmas of nearly solid densities at temperatures of several electron volts. P-24 is involved in several aspects of the physical design of Atlas, specifically in defining and designing the experimental agenda for the first several years of operation, developing advanced diagnostics to be fielded on these experiments, and fielding experiments on Pegasus and Ranchero to prepare for Atlas operation.

P-24 has responsibility for the design, testing and fabrication of the Atlas power-flow system that transports energy from energy storage capacitors to the load. The power-flow channel is the most difficult component to design because the radial forces on the conductors increase inversely as the square of radius. Thus, significant damage to hardware in the region near the load is expected. As presently envisioned, the power-flow channel will be insulated with solid-dielectric to minimize the relatively large inductance in this region. The conductors will be diskline feeding a conical line connected to the load. The conductors will be held in place during the shot by steel weights placed in contact with both transmission lines.

The Atlas Physics Design Team, which includes P-24 staff, has developed a list of the varieties of experiments to be fielded in the first 200 shots (the first two years of Atlas operation). Included on this list are experiments to investigate Rayleigh-Taylor mix, Bell-Plesset deformation of the liner, friction at high relative velocities, on-hugoniot EOS measurements, calibration of the NTS nuclear impedance-matching EOS experiments, multiple-shock EOS, quasi-adiabatic compression of materials, release isentropes, high-strain-rate phenomena, dense-plasma EOS and transport, hydrodynamics and instabilities in strongly coupled plasmas, magnetized target fusion (MTF), and high magnetic field generation. Specific experimental campaigns are now being designed to determine the diagnostic and experimental configuration requirements. As part of a successful Laboratory Directed Research and Development (LDRD) proposal, we will be assisting in the development of a variety of advanced diagnostics to be fielded on Atlas, including linear and nonlinear optical techniques, x-ray diffraction, photoelectron spectroscopy, and flash neutron resonance spectroscopy. All of these techniques are well developed for steady-state measurements, and the development effort lies in adapting them to the dynamic Atlas environment. A number of shots in FY99 have been allocated in the Pegasus imploding liner facility and the Ranchero explosively driven pulsed-power program to develop Atlas diagnostic techniques, explore liner behavior under Atlas conditions, and test certain physical components of the Atlas system.

Fig. 2 Laser driver of the Trident laser facility.

Trident Laser Facility

Trident is the multipurpose laboratory at Los Alamos for conducting experiments requiring high-energy laser-light pulses. As a user facility, it is operated primarily for inertial confinement fusion (ICF) research, high-energy-density physics, and basic research. Features include flexible driver characteristics and illumination geometries, a broad resident diagnostic capability, and flexible scheduling. A dedicated staff maintains and operates the facility and assists visiting experimenters. Target fabrication is available through the Laboratory's Target-Fabrication Facility.

The principal resource at Trident is the laser driver (Fig. 2). It employs a neodymium-doped, yttrium-lithium-fluoride (Nd:YLF) master oscillator and a chain of Nd:phosphate glass-rod and disk amplifiers in a conventional master-oscillator, power amplifier architecture. The oscillator output pulse is temporally shaped, amplified, split into two beams, amplified again, frequency-doubled, transported, and focused onto the target. A third beamline can be used as an optical probe or to provide an x-ray backlighting capability. Its pulse can be either 100 ps in length or the same length and shape as those of the main drive beams. Although the third beamline is normally operated at 527 nm, it can also be operated at 1,054 nm or 351 nm (fundamental and third harmonic output, respectively). The third beam can be timed to become active before or up to 5 ns after the main drive beams. The output of the master oscillator may also be frequency-broadened and "chirped" before amplification to allow compression to subpicosecond pulse lengths.

The main high-vacuum target chamber is a cylinder approximately 150 cm long and 75 cm in diameter. Single- or double-sided illumination of targets is possible through several 20-cm-diameter ports on each end of the chamber. More than 40 smaller ports are available for diagnostic instrumentation. Individual targets are inserted through an airlock. The target insertion and positioning mechanism provides *x*-*y*-*z* and rotation adjustment under computer control with 1-μm linear and 0.01° angular resolution. The three-axis target-viewing system has a 20-μm resolution. The chamber is fitted with a Nova standard six-inch manipulator (SIM) to accept all SIM-based instruments for checkout, characterization, or use. Trident is located in an area of the Laboratory that can accomodate both unclassified and classified research.

Optical diagnostics include illumination and backscattered-light calorimeters, backscattered-light spectrometers, and high-bandwidth (5-GHz) and streak-camera-based power monitors. Target x-ray emission is monitored by filtered, photoconductive diamond detectors and an x-ray streak camera with <10-ps resolution. Gated, filtered x-ray images covering 1 ns in 16 images are provided with 80-ps resolution by a Nova standard gated x-ray imager. Various filtered x-ray power and spectral diagnostics can be installed as needed. These cover the energy range of 0–35 keV. Static x-ray pinhole cameras are also available. Most optical and target diagnostics are available for either the main target chamber or the ultrahigh-irradiance chamber.

Trident is available to Laboratory and outside experimenters. The quality of proposed research and its relevance to Laboratory missions are major criteria in determining what experiments are fielded. Trident is operated by P-24 as a user facility that principally supports Inertial Fusion and other programs in the Nuclear Weapons Directorate. It is funded through and operated for the ICF Program Office. The resources of the Laboratory's Target-Fabrication Facility, operated by the Materials Science and Technology (MST) Division, are also available to assist experimenters in designing, fabricating, and characterizing targets for Trident experiments.

In May 1998, a second target bay and target chamber were added to the Trident Facility as part of the High Energy Density Experimental Laboratory addition to the Trident building. The target chamber was acquired from the University of Rochester Laboratory for Laser Energetics where it was the target chamber used on the original Omega 24-beam laser system. The chamber, focusing lenses, transport optics, frequency conversion crystals, and experimental diagnostics from the original Omega system were all acquired from the University of Rochester in April 1998. A ten-inch manipulator (TIM), which is the new ICF standard for positioning diagnostics, will be installed on this chamber soon, and the facility will be available for check out and testing of TIM-based diagnostics.

Over the next few years, we will upgrade the Trident laser using refurbished Nova laser components. This upgraded laser system is based on a multipass architecture with Nova 31.5-cm disk amplifiers. This new laser system would eventually have eight beamlines operating at 700 J each in 1 ns at 351 nm. Construction of the first phase (two beams) has begun. This new facility will use the Omega 24-beam target chamber, allowing great flexibility in illumination geometries. As envisioned, the Trident upgrade will remain a very flexible, high-shot-rate facility that provides a staging capability to higher energy facilities such as Omega, the future National Ignition Facility (NIF), and Sandia National Laboratory's Z pulsed-power machine. The proposed Trident Upgrade will also greatly enhance present Trident capabilities in performing experiments in laser-matter interactions and other fundamental science topics, and it will serve as an attractor for high-quality scientific research relevant to ICF and stockpile stewardship.

Inertial Confinement Fusion

The ICF program at Los Alamos is a principal component of the national ICF program. The national program is focused on the goal of achieving thermonuclear ignition in the laboratory, one of the grand scientific challenges of the 20th century. This goal is part of the broader mission to provide scientific knowledge, experimental facilities, and technological expertise to support the DOE Stockpile Stewardship Management Plan for nuclear weapons. In pursuit of the ICF mission, P-24 designs, diagnoses, executes, and analyzes the results from experiments at high-energy laser facilities worldwide. P-24 partners with other Los Alamos groups that focus on theory, modeling, and target fabrication to execute the program, with the ultimate goal of understanding laser-matter interaction physics.

***Fig. 3** Aerial view of the National Ignition Facility, a state-of-the-art, $1.2B laser facility presently under construction at Lawrence Livermore National Laboratory. This facility will be a key component in the national ICF program, which aims at achieving thermonuclear ignition in a laboratory setting.*

NIF, a state-of-the-art, $1.2B laser facility presently under construction at Livermore (Fig. 3), will be the world's most powerful laser by far and the principal focus of the national ICF program. Los Alamos and Sandia have been participating with Livermore in the design and construction of special equipment for this immense laser facility, which will be ~300 ft × 500 ft upon completion and operate at an energy of 1.8 MJ. Design and construction of the facility is currently 35% complete. In the early 1990's Los Alamos scientists collaborated with other members of the National ICF Program to establish the functional requirements and primary criteria that are the basis for this facility. Los Alamos scientists and engineers have been participating since FY93 in the conceptual, preliminary, and detailed designs of a variety of NIF subsystems. Currently, Los Alamos engineers are finishing the detailed design and beginning the engineering (fabrication, installation, and procurement) of four major subsystems: the target chamber service system, the roving mirror diagnostic assembly, the deformable mirror support structure, and the periscope (which includes the mirror support, plasma electrode Pockels cell, and polarizer support structures). P-24 is also a principal participant in the NIF Joint Central Diagnostic Team, and P-24 personnel have worked on the conceptual design for the 351-nm power and energy diagnostics and the preliminary design of a time-resolved x-ray imaging system. In addition, P-24 personnel have been involved with the management of this collaborative project.

NIF is a flexible laser, capable of greatly advancing both the ignition and weapons-physics missions. NIF is designed to drive a capsule filled with deuterium-tritium fuel to thermonuclear ignition by one of two distinct methods: direct or indirect drive. Direct drive involves the implosion of a capsule that is directly illuminated by the laser beams. Indirect drive involves laser illumination of the interior walls of a cavity (called a hohlraum) that contains the capsule. The hohlraum converts the laser energy into x-rays, which illuminate and implode the capsule very symmetrically, analogous to the process of baking an object evenly in an oven. Since both methods have different potential failure modes, both are being pursued to increase the likelihood of achieving ignition on NIF.

Considerable challenges face us in preparation for achieving fusion ignition on NIF, which will first be attempted using indirect drive. These challenges include developing novel diagnostic methods and instruments, and improving our understanding in several scientific areas, including laser-plasma instabilities, hydrodynamic instabilities, hohlraum dynamics, and dynamic properties of materials. P-24 has contributed significantly in all of these areas with target-physics experiments using present lasers: Nova at Livermore, Omega Upgrade at the University of Rochester, and Trident at Los Alamos.

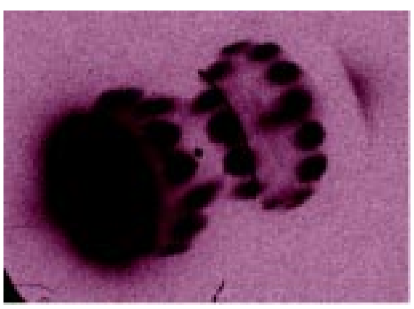
P-24 personnel have devoted considerable effort to studying laser-plasma parametric instability (LPI) processes. We have focused on Raman and Brillouin scattering, and on the novel phenomena of beam deflection by plasma flow. LPIs pose a significant threat to ignition hohlraums because they could potentially scatter most of the laser light, decreasing both the drive efficiency and the capsule illumination symmetry. During the past two years, P-24 has pursued a dual-track strategy of complementary experimental campaigns at Nova and Trident. P-24 researchers have applied the extensive Nova diagnostic suite on ignition-relevant hohlraums designed at Los Alamos, the most NIF-like plasmas ever made.

These LPI experiments on Nova are now complete, and data analysis is proceeding to complete our extensive LPI database, which will guide theoretical modeling and future experiments. The database includes calorimetry and time-resolved spectrometry of the scattered light, time-gated images of the scattered light within the target plasma, and other measurements that confirm the target plasma conditions in the hohlraum design. The scattered light measurements were done as important plasma parameters (*e.g.*, plasma density, ion species, and laser parameters like intensity, *f* number, and beam smoothing) were changed one at a time. So far, this approach has allowed us to identify qualitatively important trends in LPI processes of NIF-like plasmas, constrain emerging theoretical LPI models, and assess the threat of LPIs to ignition prior to NIF construction.

Our LPI experimental thrust has shifted to the application of new state-of-the-art capabilities and diagnostics on Trident long-scale NIF-relevant plasmas to allow more detailed measurements and comparisons of theory with experiment. These new capabilities include a nearly diffraction-limited interaction beam capable of the intensity range relevant to parametric instabilities in ignition-hohlraum plasmas. Imaging Thomson scattering now yields direct measurements of the spatial profile of important plasma parameters, such as electron density and temperature, ion temperature, plasma-flow velocity, and the location of the electrostatic waves responsible for laser scattering. We now can thoroughly benchmark the radiation-hydrodynamic codes used to design the plasma conditions in the first place. The coupling of these recent diagnostics with reflected and transmitted beam diagnostics, such as those previously implemented at Nova, already has allowed unprecedented studies of the time evolution of parametric instabilities and beam deflection. In the longer term, the plan is to exploit the fact that the single-hot-spot Trident system is sufficiently small for direct modeling by an emerging suite of codes incorporating new theoretical models. From these comparisons, we hope to develop simplified “reduced-description” models that are suitable for NIF-scale plasmas.

P-24 personnel have had important successes in advancing our understanding and capabilities in hohlraum dynamics. We have extended our understanding of and capabilities with cylindrical hohlraums, which will be used in the first indirect-drive ignition attempts on NIF. On Nova, we demonstrated control of beam deflection and its effects on capsule-illumination symmetry by spatial smoothing of the laser-beam. On Omega Upgrade, we collaborated with Livermore researchers in an important experimental series that exploited the larger number of Omega beams. As many as 40 beams were arranged into multiple beam cones (Fig. 4). These experiments constituted a first step in the development of “beam phasing,” in which beams were arranged into multiple beam cones, forming multiple rings of beam spots on the inner surface of a cylindrical hohlraum. Beam phasing will be necessary on NIF to tune both the time-integrated and time-dependent capsule-flux asymmetry by adjustment of the beam pointing and the power history in the different rings. These initial experiments have demonstrated our ability to model hohlraums incorporating multiple beams cones. We have also demonstrated unprecedented time-integrated illumination symmetry using an advanced hohlraum design developed at Los Alamos for deployment at Omega Upgrade, featuring a spherical radiation case and laser-

(a)



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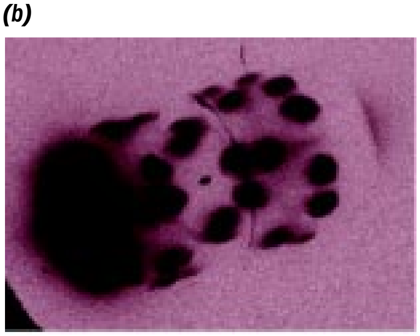


Fig. 4 Cylindrical hohlraums with single-ring (a) and two-ring (b) configurations of beam spots. Experiments with such hohlraums are the first step in developing “beam phasing,” in which many beams are arranged into multiple beam cones to control implosion symmetry.

entrance holes in a tetrahedral arrangement (see Fig. 5). Since the unique mission of Omega Upgrade is direct drive, the beams enter the target chamber in a spherical geometry, a non-optimal arrangement for cylindrical hohlraums. But tetrahedral hohlraums in Omega Upgrade can use all 60 beams and drive higher energy implosions than cylindrical implosions, an added advantage to the improved symmetry.

There was significant activity and progress in the area of hydrodynamic instability. In the NIF, capsules with cryogenic fuel will have to be compressed to large convergence ratios (about 30) in order to ignite. Convergence is ultimately limited by hydrodynamic instability. To date, laser-driven capsule implosions have only achieved moderate convergence ratios (below 10), due at least in part to the known limitations of past laser systems, including Nova. During the past two years, P-24 fielded the initial attempts at implosions of double-shell capsules, first at Nova and subsequently at Omega Upgrade, in tetrahedral hohlraums.

Double shell capsules are an attractive alternative for NIF because they do not require cryogenics for ignition, although they are potentially more hydrodynamically unstable than single-shell capsules. The improved illumination symmetry in tetrahedral hohlraums now allows reasonable attempts at high-convergence implosions with double-shell capsules prior to deployment of the Omega Upgrade cryogenics system.

The first experimental series with Omega Upgrade capsules did not reach the predicted performance. Potential culprits have been identified and further investigation is proceeding. P-24 hydrodynamics research has also focused on cylindrical implosion targets, which are much easier to diagnose than capsules and yet retain important convergent effects (see the research highlight on this topic in Chapter 2). P-24 researchers have completed a study of the nonlinear growth of multi-mode perturbations in x-ray-driven cylindrical targets due to the ablative Raleigh-Taylor (RT) instability on Nova, and the results were in good agreement with theoretical modeling. Moreover, there was spectacular success in deploying direct-drive cylindrical implosions of Los Alamos design, capable of significantly higher RT growth than the indirect-drive design. Our initial single-mode RT experiment showed significantly lower growth factors than predicted, and additional investigation is proceeding.

In collaboration with other groups in the Laboratory's Physics, Applied Theoretical and Computational Physics (X), and Dynamic Experimentation (DX) Divisions, as well as Oxford University, the University of California at San Diego, Sandia, and Livermore, P-24 is using the Trident laser system to pursue studies of the dynamic properties of materials that are of interest to the ICF Program and

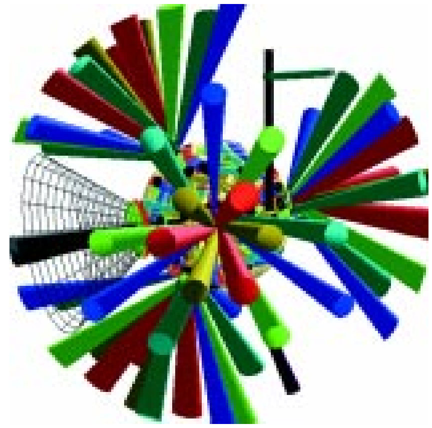


***Fig. 5** 3-D schematic of a spherical radiation case with tetrahedral symmetry. This design allows for use of all 60 Omega Upgrade laser beams to drive a higher-energy implosion with improved symmetry.*

to weapons science. The Trident laser is used to drive high-pressure (from tens of kilobars to several megabars), temporally shaped shocks into condensed materials under study. Separate beams of the laser system can be used to create accurately synchronized, powerful x-ray and optical pulses that are used for probing the shocked material. Using this configuration, the group has developed new diagnostic methods such as transient x-ray diffraction (TXD). TXD has in turn been used to measure the dynamic properties of phase changes in materials.

The methods developed on Trident are being applied to materials of central interest to ICF, such as beryllium. One of the ultimate goals of this research program is detailed characterization of beryllium alloys such as beryllium-copper. These materials will be used as the ablator in advanced, Los Alamos-designed ignition capsules with superior hydrodynamic stability. Exact determination of the melt transition in these materials is crucial for predicting their hydrodynamic behavior during implosion. The temporally resolved measurements of solid-solid phase transitions that have already been demonstrated are an important precursor to measurement of melt dynamics.

P-24 personnel deployed several diagnostics and support systems for the ICF program. The biggest effort was associated with Omega Upgrade. An optical Cassegrain microscope, which fits in the standard ten-inch reentrant diagnostic manipulator, was fielded successfully and is already in use for Los Alamos campaigns. This instrument has added the capability to diagnose the propagation of shocks (and thus hohlraum radiation temperature) by detecting the shock breakout from a calibrated material sample. P-24 has also deployed the Omega "bang-time" diagnostic, part of the customary diagnostic suite for capsule implosions. The Kirkpatrick-Baez x-ray microscope previously deployed by P-24 at Omega was the beneficiary of a major upgrade. A target metrology station for Omega, engineered and deployed by P-24, has proven to be another success.

Closer to home, a local x-ray calibration facility has been set up to test various x-ray diagnostics under development in P-24 and to maintain existing ones. This facility should eliminate the wasteful use of laser system shots for such purposes. Looking towards our future on NIF, P-24 completed the conceptual design for the time-resolved x-ray imaging system, a Phase-1 NIF diagnostic. Moreover, we have demonstrated successfully the rapid-pad-polishing technique for NIF optical fabrication, which is now moving to the production stage.

High Energy Density Experiments in Support of Stockpile Stewardship

P-24 performs laser and pulsed-power-based experiments that are intended to enhance understanding of the basic physical processes that underlie nuclear weapons operation. In collaboration with weapons designers and other theoreticians, these experiments are designed to address issues in areas such as radiation hydrodynamics, fluid instabilities, shock wave physics, and materials science. The experiments use the Trident laser and the Pegasus pulsed-power machine at Los Alamos, and also larger facilities including the Nova laser, the Omega laser, the Helen laser at the Atomic Weapons Establishment (AWE) Laboratory in the United Kingdom, and Sandia's Z pulsed-power machine. We have formed strong world-wide collaborations in the disciplines central to high energy density physics.

Current work in the group includes

- nonlinear fluid instability studies driven by a variety of pressure sources;
- imploding liner studies of the basic nature of material friction;
- propagation of structured shocks in a variety of media (Fig. 6);
- development of transient x-ray diffraction for the study of solid phase changes, plastic flow, and other materials phenomena;
- study of the implosion of cylindrical and spherical shells with various defects;
- study of high-energy, laser-based x-ray radiography for diagnosis of fluid instability experiments; and
- study (in collaboration with Sandia) of the fundamental properties of beryllium that are of interest to inertial fusion and other applications.

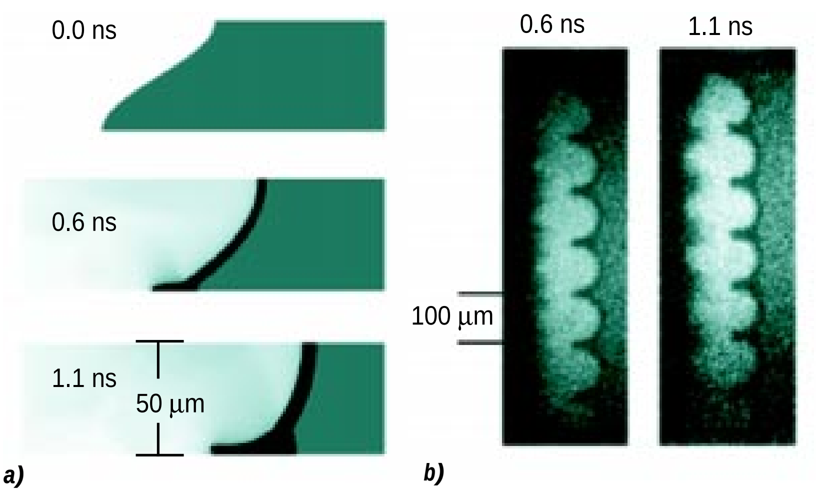


***Fig. 6** A simulation of a half-wavelength segment (a) and experimental data for five to six full wavelengths (b) of a temporally shaped shock propagating in brominated polystyrene. This exeriment was designed and fielded at the Nova laser by Los Alamos personnel.*

In the pursuit of our research, we are developing advanced diagnostic measurement systems. This work includes research on very high-resolution x-ray imaging that will be applied to hydrodynamic, shock-wave, and materials experiments. We also pursue research in fundamentally improving the quantitative analysis of temporally gated x-ray imaging.

Magnetic Confinement Fusion

Magnetic fusion energy research, and its associated science, is an important constituent of P-24's plasma physics portfolio. We are capitalizing on the recent strategic shift in national fusion research priorities, to increase the emphasis on innovative fusion confinement approaches. To that end, P-24 is working with the Los Alamos Magnetic Fusion Energy (MFE) Program office to develop new low-cost concepts for fusion energy. Central to this effort is magnetized target fusion (MTF), a truly different fusion concept intermediate in density between traditional magnetic fusion and inertial fusion. We specifically propose to form and preheat a compact toroid target plasma using well-established techniques, and then compress this target plasma with imploding liner technology developed by DOE defense programs (Fig. 7).

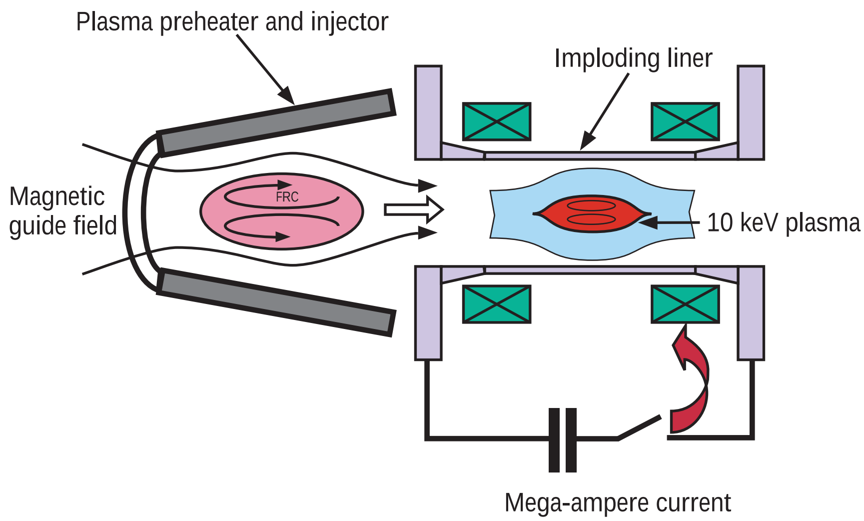


Fig. 7 A schematic of the Los Alamos MTF experiment. A dense, field-reversed configuration (FRC) target plasma is formed and translated into a 10-cm-diameter, 30-cm-long aluminum liner (flux conserver). The liner is subsequently imploded to a final diameter of 1 cm at velocities up to 1 cm/μs. The compressed plasma will reach 5 to 10 keV under adiabatic compression if losses can be kept low.

Three technical considerations explain why research in the MTF density regime is important. First, fusion reactivity, which scales as density squared, can be increased by many orders of magnitude over conventional MFE. Second, all characteristic plasma scale-lengths decrease with density. Hence, system size is naturally reduced at a high density. Third, magnetic insulation greatly reduces the required power and precision to compressionally-heat a plasma to fusion-relevant conditions compared with ICF, and brings the pulsed-power requirements for adiabatic plasma heating within reach of existing facilities. The future path for engineering development of MTF as an economic power source is less well-defined than for the more mature approaches of MFE and ICF. However, a number of possibilities are being discussed, and our research program will include scoping studies to identify the most promising approaches. If successful, MTF will achieve high performance fusion conditions with soon-to-be-realized pulsed-power facilities such as Atlas.

Historically, Los Alamos has had significant involvement in developing alternate approaches to fusion. This precedent has guided our development of collaborative programs with Columbia University, the University of Washington, Livermore, and the Princeton Plasma Physics Laboratory. In all four collaborations, we employ our engineering, physics, and diagnostics expertise to aid the development of exciting fusion concepts.

Our collaboration with Columbia University produced high-power amplifiers to suppress magnetohydrodynamic activity in the high-beta (HBT-EP) tokamak experiment. In collaboration with the University of Washington, we are developing a high-power modulator to drive plasma current in a field-reversed configuration (FRC) experiment by means of rotating magnetic fields. FRCs belong to the compact toroid class of fusion approaches and promise efficient magnetoplasma confinement with simple, compact reactor configurations. Our University of Washington collaboration current-drive experiments are central to the notion of steady-state FRC operation.

Two new experimental collaborations are also underway. We are joining with Livermore to take the next step in sustained spheromak confinement research. The Sustained Spheromak Physics Experiment, under construction at Livermore, was designed to achieve high plasma performance under quasi-steady-state conditions. Los Alamos expertise, developed over years of research on the Compact Torus Experiment spheromak, will be an important contributor to the success of this effort. We are also joining the national research team on the National Spherical Torus Experiment under construction at the Princeton Plasma Physics Laboratory. This experiment will investigate the confinement properties of very low-aspect-ratio tokamaks with a view to achieving efficient (high-beta) confinement in a compact toroidal system.

Applied Plasma Technologies

P-24 develops and uses advanced plasma science and technology to solve problems in defense, the environment, and industrial manufacturing. The group has achieved international status and recognition in this pursuit, including two recent R&D 100 awards. The first R&D 100 award, presented in 1996, was in recognition of the development of the PLASMAX system, which takes advantage of plasma sheath properties combined with mechanical vibration to rapidly and effectively clean semiconductor wafers without water or other liquid solvents. The second R&D 100 award, presented in 1997, recognized the efforts of a multidisciplinary group (both Laboratory and industrial personnel) in the initial commercialization of plasma source ion implantation (PSII) (see the discussion below and the research highlight on this topic in Chapter 2). Major technology-development and program elements within the group include the following:

Atmospheric-Pressure Plasma Jet

A nonthermal, uniform-glow discharge at atmospheric pressure in a cylindrical cavity with high gas-flow rates produces reactive radicals and metastables persisting for fractions of a second at atmospheric pressure. These reactive species remove surface contaminants and films, providing a new means of cleaning objects and substrates (Fig. 8). Current programs include chemical and biological decontamination for the neutralization of chemical agents on surfaces and graffiti removal.

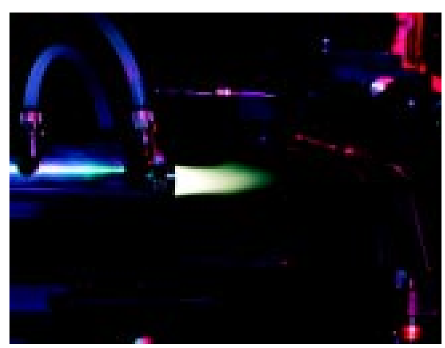


Fig. 8   The atmospheric pressure plasma jet in operation, with a reactive gas stream exiting from the source.

Intense, Pulsed Ion Beams and Accelerated Plasmas

Several promising applications of intense ion beams and pulsed accelerated plasmas have emerged in the past few years. These include processing of materials, including surface modification through rapid melt and resolidification, ablative deposition for producing high-quality coatings, and nanophase powder synthesis; production of intense neutral beams for the next generation of tokamaks; and intense, pulsed neutron sources for the detection of nonmetallic mines, neutron radiography, neutron resonance spectroscopy, and spent nuclear fuel assay. We are nearing completion of two devices that address these applications: an intense, repetition-rated ion accelerator known as the continuous, high-average-power microsecond pulser (CHAMP), and an accelerated plasma source known as the magnetoplasma processing tool (MPT).

CHAMP will produce a 12-kA, 250-keV, 1-μs ion beam from any gas puffed into its magnetized anode. This beam is ballistically focused to a 25- to 100-cm^2 spot, resulting in energy fluxes of tens of J/cm^2—enough to ablate the surface material. Lower energy fluxes can be obtained by working out of the focal plane. Due to the low gas-loading of this anode and the design of the accelerator, this technology is capable of being operated at 30 Hz, although as constructed CHAMP will operate at about 1 Hz. Calculations suggest that by hitting a tritiated metal target with a deuteron beam, a microsecond pulse of 2×10^{12} DT neutrons could be produced in a device sufficiently portable to be fielded at experimental sites throughout the Laboratory.

The MPT produces a 10- to 30-kV accelerated plasma of any gas, and is capable of delivering up to 4 J/cm^2 over 1,000 cm^2 in a 200 μs pulse at an electrical-to-directed energy efficiency of up to 50%. Like CHAMP, this device can be transported easily. Applications include rapid, wide-area treatment of materials, such as etching and crosslinking of polymer surfaces.

Plasma-Source Ion Implantation and Cathodic Arcs

PSII is a non-line-of-sight method for implanting ions from a plasma into a target (usually, but not necessarily a conducting material) to achieve beneficial surface modifications. Typically, ions in plasma produced from a gaseous precursor are used, but cathodic arc technology allows metal ions to be implanted as well. PSII may be seamlessly combined with plasma-based surface-coating technologies to form highly adherent, relatively thick (many microns) coatings of materials such as diamond-like carbon (DLC) and ceramic metal oxides. Past and present programs include development of plasma-implanted and plasma-deposited erbia coatings in support of the weapons surety program; molten-plutonium-resistant coatings for near-net-shape casting molds;

highly adherent refractory coatings for wear- and corrosion-resistant gun barrels for the Army; and plasma-based surface treatment and adherent coatings for industrial tooling. The industrial support for research and development (R&D) in this area is part of a National Institute of Science and Technology (NIST) Advanced Technology Program with more than a dozen industrial partners.

Silent-Electrical and Pulsed-Corona Discharges

Nonthermal plasmas (NTPs), sometimes called nonequilibrium or "cold" plasmas, are characterized by conditions in which the various plasma species are not in thermal equilibrium—that is, electrons, ions, and neutral species have different temperatures, with the less massive electrons having the highest temperature (*e.g.*, 1–10 eV). Such plasmas are good sources of highly reactive oxidative and reductive species and plasma electrons. Via these reactive species, one can direct electrical energy into favorable gas chemistry through energetic electrons. NTPs can be easily created by an electrical discharge in a gas. Two example NTP reactors, a silent-discharge plasma reactor and a pulsed-corona reactor, are shown in Fig. 9. Both use the mechanism of transient electrical discharge streams to produce energetic electrons and associated active species in the process gas.

We are applying atmospheric-pressure NTP processing to hazardous-chemical destruction, pollution control, and chemical synthesis. The hazardous-chemical-processing and pollution-control applications range from the treatment of hydrocarbon and halocarbon compounds (many solvents) that are entrained in soil and water or are emitted as stack gases, to the treatment of oxides of nitrogen (nitric oxide, in particular) in flue and engine-exhaust gases. Our work has spanned the regimes of bench-scale studies to actual field demonstrations of this technology. Our more recent interests are directed toward the synthesis of higher-order hydrocarbon fuels from methane. Research in the area of NTPs represents a fusion of the fields of electrical-discharge physics, plasma chemistry, and pulsed power.

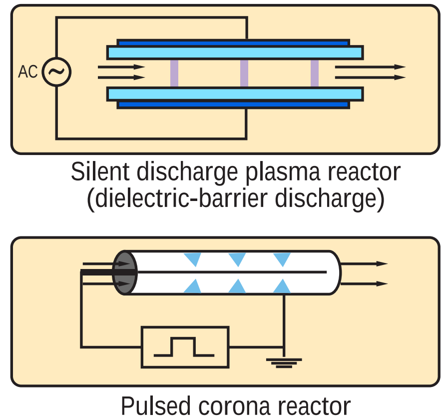


Fig. 9 Schematic drawings of silent-discharge plasma and pulsed-corona reactors. These reactors use an electrical discharge in a gas to create nonthermal plasmas that can be used for such purposes as destroying hazardous chemicals, controlling pollutants, and synthesizing chemicals.

Further Information

For further information on all of P-24's projects, refer to the project descriptions in Chapter 3. Some of our major achievements are also covered as research highlights in Chapter 2. These include our work at the Trident facility, our current PSII developments, cylindrical and spherical implosion research at Nova and Omega, and development of an infrared imaging bolometer for use in fusion plasma research.

P-25: Subatomic Physics

Andrea P. T. Palounek,
Group Leader

Michael J. Leitch,
Deputy Group Leader

Introduction

The Subatomic Physics Group (P-25) is engaged primarily in fundamental nuclear and particle physics research. Our objective is to conduct diverse experiments that probe various aspects of subatomic reactions, providing a more thorough understanding of the basic building blocks that make up our universe. Although our main focus is basic research, there is also a strong and growing effort to turn the group's skills and capabilities to applied programs such as proton radiography. To conduct our research, we often participate in large-scale collaborations involving physicists from universities and institutions around the world, and we participate in and lead experiments at a variety of facilities. Currently, we are conducting research and developing new programs at Los Alamos National Laboratory and other laboratories, including Brookhaven National Laboratory and Fermi National Accelerator Laboratory (Fermilab). The following sections highlight the significant experiments and activities that we are currently pursuing.

Hypernuclei Physics

One of our key interests over the past several years has been the study of lambda (λ)-hypernuclei, where the λ replaces a neutron within nuclei, to explore the strong interaction (the force that holds the nucleus of an atom together). In 1994, we proposed experiment 907 (E907) at Brookhaven's Alternating-Gradient Synchrotron (AGS) to study the feasibility of using the (K^-,π^0) reaction (in which a negative kaon decays to a neutral pion) as a novel tool to produce λ-hypernuclei with energy resolutions significantly better than those produced in the previous (K^-,π^-) and (π^+,K^+) experiments (in which negative kaons decay to negative pions and positive pions decay to positive kaons, respectively). E907 should also be capable of measuring the π^0 weak-decay modes of λ-hypernuclei, which have never been studied before. The LANSCE Neutral Meson Spectrometer (NMS) and associated equipment were moved to the AGS for this experiment. A new data acquisition system and a new array of active target chambers were also successfully installed. Preliminary measurements have provided the first hypernuclear spectrum using the (K^-,π^0) reaction. In addition, the π^0 energy spectrum resulting from the weak-decay of light λ-hypernuclei has also been measured. Data collection has been completed and the data are currently being analyzed.

The PHENIX Program at RHIC

P-25 has also been exploring the subatomic physics that defined the universe at its beginning. Big Bang cosmology pictures a time very early in the evolution of the universe when the density of quarks and gluons was so large that they existed as a plasma, not confined in the hadrons we know today (neutrons, protons, pions, and related particles) (Fig. 1). In 1999, when operations commence at Brookhaven's Relativistic Heavy-Ion Collider (RHIC), it should become possible to create a small sample of such primordial quark-gluon plasma in the laboratory and study its exotic properties. The

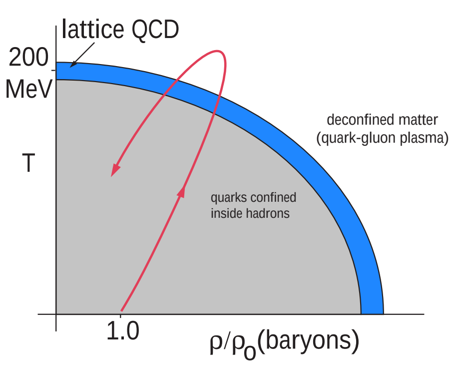


***Fig. 1** Lattice QCD calculations predict that at higher temperatures and densities, there will be a transition of matter from the confined state to the deconfined state, as shown by the solid band. Research with RHIC will explore this transition of matter.*

challenge facing the international collaborators involved in the RHIC program is to find the signatures of the fleeting transition into this deconfined phase of matter. Extending the Physics Division's long history of experiments at the energy frontier, P-25 is playing a major role in defining the physics program for RHIC.

P-25 is also playing a key role in constructing two major subsystems for the PHENIX detector, one of two major collider detectors at the RHIC facility. The PHENIX collaboration currently consists of over 400 physicists and engineers from universities and laboratories in the U.S. and nine foreign countries. Our work focuses on the multiplicity/vertex detector (MVD) and the muon subsystem. The MVD is the smallest and among the most technically advanced of the PHENIX systems. It will be located very close to the region where the two beams of 100-GeV nucleon ions intersect. Its function is to give the precise location of the interaction vertex and to determine the global distribution and intensity of secondary charged-particle production, which is a crucial parameter in fixing the energy density achieved in the collision fireball.

The muon subsystem, the largest of PHENIX's subsystems, consists of two large conical magnets and associated position-sensitive tracking chambers at opposite ends of the detector. Muons are identified by recording their penetration of a series of large steel plates interspersed with detection planes, all of which follow the magnets at each end of the detector. The muon subsystem plays a central role in P-25's physics agenda at RHIC. It is optimized for examining experimental observables at very high temperatures and densities, at which the strong force is smaller and easier to calculate using perturbative quantum chromodynamics (QCD).

RHIC is currently scheduled to begin operations in late 1999, and first results are expected in 2000.

High-Energy Nuclear Physics

Another area of study in P-25 is parton distribution in nucleons and nuclei, and the nuclear modification of QCD processes such as production of J/ψ particles (made up of a pair of charm/anti-charm quarks). We are currently leading a research program centered on this topic at Fermilab. This program (which is discussed further in a research highlight in Chapter 2) began in 1987 with measurements of the Drell-Yan process in fixed-target proton-nucleus collisions (see Fig. 2). These measurements showed that the antiquark sea of the nucleon is largely unchanged in a heavy nucleus. In our most recent measurements during the NuSea Experiment (E866), we also showed that there is a large asymmetry between down and up antiquarks, presumably due to the nucleon's pion cloud (Fig. 3). In addition we showed that the production of heavy vector mesons such as the J/ψ is strongly suppressed in heavy nuclei. We mapped out this effect over a broad range of J/ψ energies and angles. Although the causes of this suppression are not yet fully understood, it is already clear that absorption in the final state

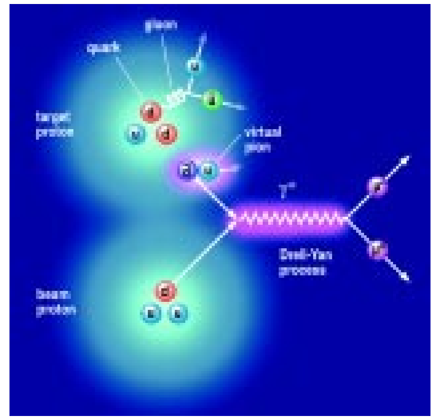


***Fig. 2** A proton consists of three valence quarks held together by gluons in a sea of quark-antiquark pairs. These pairs may be produced by gluon splitting, a symmetric process generating nearly equal numbers of anti-down, $\bar{d}$, and anti-up, $\bar{u}$, quarks, or from virtual-pion production, an asymmetric process that generates an excess of $\bar{d}$. We can determine $\bar{d}/\bar{u}$ by measuring the properties of the muon pairs produced in the Drell-Yan process, which occurs when a quark in a proton beam strikes a sea antiquark in a target.*

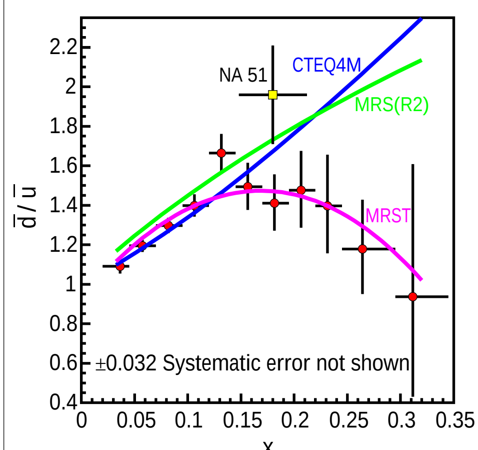


***Fig. 3** The ratio of $\bar{d}$ to $\bar{u}$ in the proton from the FNAL E866 NuSea data as a function of the fraction of the proton's momenta carried by the quark, x. NA51 was the only previous measurement of this quantity. The curves represent various parameterizations of $\bar{d}/\bar{u}$. The curve that best matches that data, labeled "MRST," was proposed only after the FNAL E866 NuSea data were published.*

plays an important role, as do energy-loss of the partons and shadowing of the gluon distributions. Data analysis is nearly complete, and continuing experiments at Fermilab have been proposed.

Liquid Scintillator Neutrino Detector

P-25 also conducts experiments to explore the possibility of neutrino oscillation, which has great implications in our understanding of the composition of the universe. The Liquid Scintillator Neutrino Detector (LSND) experiment at LANSCE has provided evidence for neutrino oscillations, revealing an excess of oscillation events in both the muon-antineutrino to electron-antineutrino ($\bar{\nu}_\mu \rightarrow \bar{\nu}_e$) and muon-neutrino to electron-neutrino ($\nu_\mu \rightarrow \nu_e$) appearance channels. These two channels are independent of each other and together provide strong evidence for neutrino oscillations in the $\Delta\left(m^2\right) > 0.2\ \mathrm{eV}^2$ region. The LSND results, therefore, imply that at least one of the neutrino types in each of these appearance channels has a mass greater than 0.4 eV, a contradiction to standard models that assume neutrinos have no mass. Based on estimates of the number of neutrinos present in the universe, the LSND results suggest that neutrinos contribute more than 1% to the mass density of the universe. The existence of neutrino oscillations has great significance for nuclear and particle physics as well because it means that lepton number is not conserved and that there is mixing among the lepton families, which contradicts the standard models. The LSND experiment, which had its last run in 1998, has also made precision measurements of neutrino-carbon and neutrino-electron scattering, which is of interest for testing the weak interaction.

Booster Neutrino Experiment

As an extension of the work conducted during the LSND experiment, P-25 has been pursuing the Booster Neutrino Experiment (BooNE), which will make a definitive test of the LSND neutrino oscillation results. This experiment will also be conducted at Fermilab. The BooNE detector will consist of a 12-m-diameter sphere filled with 770 tons of mineral oil and covered on the inside by 1,220 phototubes recycled from the LSND experiment (Fig. 4). The detector will be located 500 m away from the neutrino source, which will be fed by Fermilab's 8-GeV proton booster. The proton booster will run nearly continuously, and if the LSND results are indeed due to neutrino oscillations, BooNE will observe approximately 1,000 $\nu_\mu \rightarrow \nu_e$ oscillation events after one year of operation. Furthermore, if oscillations are observed, BooNE will be able to make precision measurements of the oscillation parameters and test for charge-conjugation parity violation in the lepton sector. The BooNE detector should be operational by the end of 2001, and first results are expected a year later.

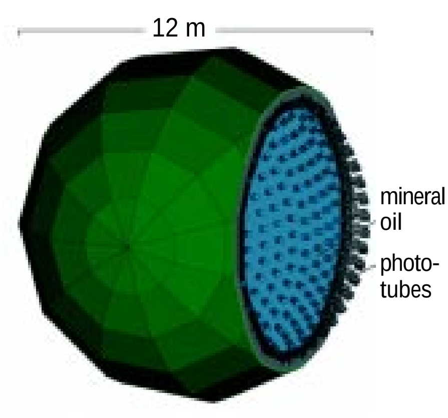


Fig. 4 Conceptual view of the BooNE detector, which will provide a definitive test of the LSND evidence for neutrino oscillations.

MEGA

The apparent conservation of muon number remains a central problem of weak interaction physics, and is thus another area of research in P-25. Experimental evidence to date shows that muons consistently decay into an electron and two neutrons. However, the particle physics community is continually searching for instances that violate muon number conservation, which would give insight into possible extensions of the minimal standard model of weak interactions. MEGA was an experimental program designed to make such a search at the Los Alamos Meson Physics Facility (LAMPF), now known as LANSCE. MEGA, which searched for muon decays yielding an electron and a gamma ray (hence, the acronym), completed its data collection in 1995. The extraction of kinematic properties for all of the muon decay events that potentially meet the MEGA criteria is now complete, and the final sample of about 5,000 events is under careful scrutiny. The combined data from the summers of 1993–1995 are expected to yield a statistical precision that improves the current world sensitivity to this process by a factor of 25 to roughly 3×10^{-12}.

Rho

As part of the MEGA program, the MEGA positron spectrometer was used to measure the Michel parameter ρ (rho), which governs the shape of the polarization-independent part of the energy spectrum for positrons emitted in normal muon decay. The standard model predicts ρ to be 0.75; based on experimental results to date, it is known to be within 0.3% agreement with that value. Deviations from 0.75 might indicate the need for right-handed currents in the standard model. In our experiment, the energy spectrum for over 2×10^8 positrons was recorded and data were taken under several conditions to help with the analysis of systematic errors. Despite these precautions, we anticipate that energy-dependent systematic errors will limit the accuracy of the result to a level that is currently being evaluated. Analysis of the data is scheduled for completion in 1999.

Electric Dipole Moment of the Neutron

P-25 is also participating with the Neutron Science and Technology Group (P-23) in a Laboratory project aimed at improving the limit on the electric dipole moment (EDM) of the neutron. Our interest in this topic is driven by the recent observation of violation of time reversal invariance in the neutral kaon (K^0) system. Many theories have been developed to explain this time-reversal-invariance violation, but most have been ruled out because they predict a sizable EDM for the neutron, which experiments have yet to verify. Today, new classes of highly popular models, such as supersymmetry, predict EDM values that are potentially within the reach of experiment. In addition, if the observed baryon-antibaryon constitution of the universe is due to time-reversal-violating symmetry breaking at the electroweak scale, the range of predicted EDM values is also measurable. We are currently working towards experimentally verifying the feasibility of conducting an experiment that should improve the limit on the neutron EDM by two orders of magnitude to 4×10^{-28} e*cm.

Fundamental Symmetry Measurements with Trapped Atoms

With the advent of optical and magnetic traps for neutral atoms, a new generation of fundamental symmetry experiments has arisen that exploit point-like, massless samples of essentially fully polarized nuclei. In P-25, we are pursuing a measurement of the beta-spin correlation function in the beta decay of ^{82}Rb confined to a time orbiting potential (TOP) magnetic trap as a means to probe the origin of parity violation in the weak interaction (see the research highlight on this topic in Chapter 2). We also envision a new generation of atomic-parity nonconservation experiments that test the neutral current part of the weak interaction. In the latter experiments, measurements of the beta-spin correlation function with a series of radioactive isotopes of cesium and/or francium could eliminate atomic structure uncertainties that presently limit the ultimate precision of beta-spin correlation function measurements. This should improve the quality of our results.

Ultracold Neutrons

P-25 is also participating with P-23 in experiments to provide better sources of UCN, which can be trapped to study neutron properties. Solid deuterium converters have been proposed as a source of UCN for some time. Recently, experiments conducted in the Physics Division have made it clear that coupling a solid deuterium moderator to the high cold-neutron densities available from a pulsed spallation neutron source, such as the Los Alamos Proton Storage Ring, may provide a UCN source with several orders of magnitude higher neutron density than reactor driven sources such as the Institute Laue-Langevin source.

Theory

In addition to the fundamental research conducted in our group, P-25 has a strong theory component, which consists of a staff member and a number of short- and medium-term visitors from universities and laboratories throughout the world. Theoretical research focuses on basic issues of strong, electromagnetic, and weak interactions topics that complement the present activity of the experimental program and that impact possible future scientific directions in the group. As such, our theoretical component facilitates interaction between experimental and theoretical activities in the nuclear and particle physics community and contributes to a balanced scientific atmosphere within the group. Recent theoretical activity has focused on neutrino interactions and masses, parity violation in chaotic nuclei, deep inelastic scattering, hadron properties in free-space and in nuclei, and QCD at finite temperatures.

Proton Radiography

Although our main focus is basic research, P-25 also has several applied programs, such as proton radiography. There are two goals for the proton radiography program. The first is to demonstrate that high-energy proton radiography is a suitable technology for meeting the goals established for the advanced radiography program; the second is to develop the capability of 800-MeV proton radiography for meeting immediate programmatic needs. These goals are highly coupled since many of the techniques developed for 800-MeV radiography can be used at higher energies. Most of our effort in the last year was focused on the 800-MeV program because funding restrictions limited progress in our planned 25-GeV demonstration at Brookhaven's AGS. We are currently exploring the possibility of building a 50-GeV machine, the proton radiography interim-step machine (PRISM) that will be dedicated to proton radiography experiments (Fig. 5). For more information on our proton radiography efforts, refer to the research highlight on this topic in Chapter 2.

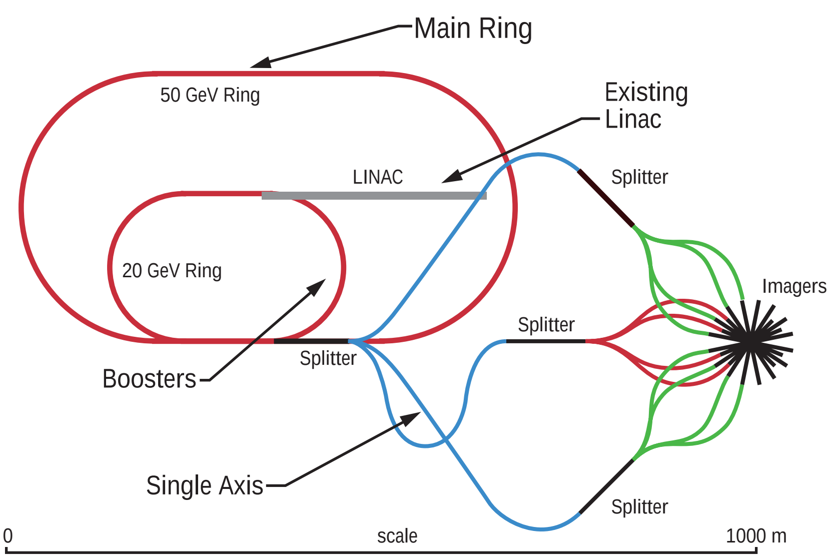


***Fig. 5** Concept of the proton radiography Advanced Hydrotest Facility (AHF). PRISM, a subset of the AHF, would include the linac injector, the main 50-GeV acceleration ring, a single-axis extracted beam line, a firing point, and a lens system.*

Quantum Computation using Cold, Trapped Ions

In another applied program, P-25 is collaborating with P-23 to develop quantum computation technology. Quantum computation is a new computational paradigm that is much more powerful than classical computation because it allows computing with quantum-mechanical superpositions of many numbers at once. In a quantum computer, binary numbers will be represented by quantum-mechanical states ("qubits"). We are developing a quantum-computational device in which the qubits will be two electronic states of calcium ions that have been cooled with a laser to rest in an ion trap. Once these ions are resting in the trap, we will perform quantum logical operations with a laser beam that is resonant with the qubit transition frequency and is directed at individual ions. We have recently succeeded in trapping and imaging a cloud of calcium ions using two titanium-sapphire lasers, one frequency-doubled to 397 nm, the other to 866 nm. Future experiments will focus on increasing the number of ions that are simultaneously trapped, which will move us closer to realizing a functioning quantum computation system.

Carbon Management and Mineral Sequestration of CO_2

P-25 is also focussing on ways to solve global environmental issues, such as the overabundance of carbon dioxide (CO_2) in the atmosphere. Today, fossil fuels account for 80–85% of total world energy use. The reasons for this include their abundant supply, high energy-density, public acceptance, ease of use and storage, existing infrastructure, and, most importantly, their low cost. The only threat to their continued widespread use is the possible environmental consequence of the vast amounts of CO_2 released into the atmosphere as a result of their combustion. The use of fossil energy has raised the level of CO_2 in the atmosphere by roughly 30% since their earliest use, and emissions could reach 10 times current levels in the next 50 years as populations grow and the standard of living improves worldwide. Thus, mitigation of these CO_2 emissions is becoming an important global issue. P-25 is participating in a Laboratory-wide program to apply scientific expertise to the CO_2 issue. Our proposed solution to this problem is to react CO_2 with common mineral silicates, which exist in quantities that far exceed the world's coal reserves, to form carbonates like magnesite or calcite. These reactions are exothermic and thermodynamically favored under ambient conditions. Thus, this disposal option can easily address the CO_2 problem in a safe and permanent manner that also promises to be relatively inexpensive. We are currently participating in experiments with other Laboratory divisions to demonstrate the soundness of this proposal.

Education and Outreach

P-25 group members continue to be active in education and outreach activities, both as participants in programs sponsored by the Laboratory and as individual citizens who volunteer their time for various activities. Recent group member activities include acting as judges for the New Mexico Supercomputing Challenge, serving as consultants for the Teacher Opportunities to Promote Science (TOPS) program, participating in career days and college days at New Mexico schools, and visiting local classrooms. We also coordinated, organized, and participated in the Teacher's Day at the annual meeting of the American Physical Society's Division of

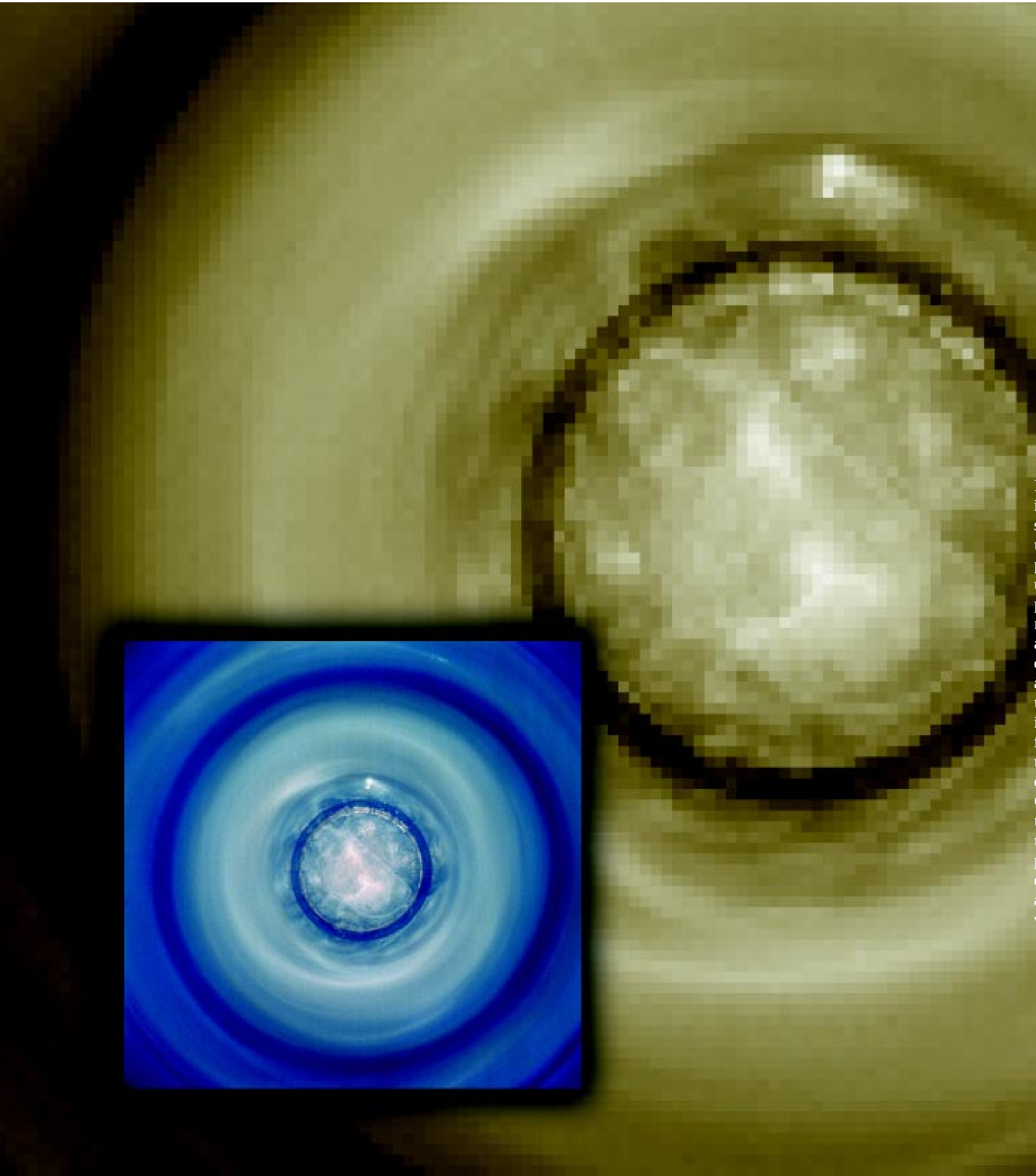
Nuclear Physics.

In addition to these outreach activities, P-25 sponsors several high school, undergraduate, and graduate students to work on projects within the group. Through their individual schools, these students study computing, engineering, and electromechanical technical support, as well as physics, and they supplement their learning through interaction with Laboratory mentors and real on-site experience. Several students are writing theses based on the work they do at P-25.

Further Information

All of the research described is aimed at increasing our understanding of subatomic reactions, and we are poised to make exciting discoveries in nuclear and particle physics over the next several years. To learn more about these projects, as well as the other work being conducted in our group, please see the project descriptions in Chapter 3. Some of our major achievements are also covered as research highlights in Chapter 2. These include our work in high-energy nuclear physics and proton radiography.

2. Research Highlights



Physics Division is developing an intense ultracold neutron (UCN) source that will make it possible to study the fundamental properties of the neutron with unprecedented sensitivity. To produce the UCN source, fast neutrons from the LANSCE accelerator will be moderated into cold neutrons and made to strike a volume of frozen deuterium at the base of the cylindrical cryostat in our apparatus (right). The frozen deuterium cools and slows the neutrons into UCN, which can then be used for experiments. Currently, we are exploring how the purity and crystal structure of the deuterium affect UCN production and collection efficiency. The image at left shows a sample of frozen deuterium with visible impurities.

The Birth of Structural Genomics

J. Berendzen and L. Flaks (P-21); and J. Newman, M. Park, T. Peat, G. Waldo, and T. C. Terwilliger (LS-8)

Introduction

Profound scientific discoveries can change not only the direction and scope of research, but also the way people look at their place in the universe. Consider geography in the time of Magellan, or physics in the early 20th century. Researchers in those times must have viewed the data being produced by new instruments with surprise, wonder, confusion, and elation, for they were the first ones to see the world in a new way. At the end of the 20th century, the streams of data from biology and affiliated disciplines are eliciting a similar mixture of emotions. The discoveries being made in these fields may well mark this page of history as the era in which a comprehensive understanding of the machinery of life finally became possible. This new understanding will become the basis for new technologies and industries and will likely change the way we view ourselves.

Modern molecular biology has developed tools for rapidly determining the complete sequence of DNA bases of an organism, known as its genome (Fig. 1). The revolution in biology is being driven by genomics, and at the moment the exemplary technology of the revolution is the automated DNA sequencer. In 1998, sequencing was completed for genomes of six different microbial organisms, typically pathogenic organisms or ones from exotic environments, each a few megabases in length. By the time you read this, it is likely that the aggregate output of genome sequencing projects worldwide will be greater than one megabase per day and that sequencing a microbial genome will be more routine than a space shuttle flight. In a spectacular accomplishment, the first genomic sequence of an animal—a tiny roundworm called *C. elegans*—was completed in December 1998. Four years from now, it is expected that sequencing of the three gigabase human genome will be complete. With the revolution firmly launched in DNA sequencing, it became clear over the last year to many researchers that it is time to move beyond linear DNA sequences to the three-dimensional (3-D) structures and the functions of the proteins that the DNA encodes.

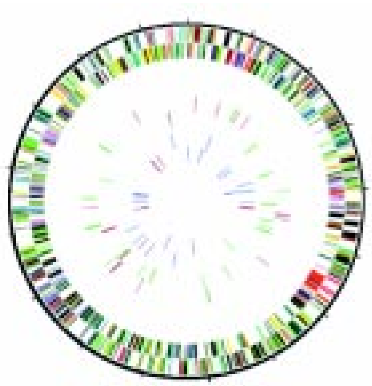


***Fig. 1** A microbial genome in map form. Each colored bar represents a different protein.*

Protein Structures

Our research centers on the determination and analysis of protein structures. The predominant technology for determining these structures is x-ray crystallography, although multidimensional nuclear magnetic resonance spectrocopy of isotopically-labelled proteins is making an increasing contribution in this area. A structure consists of the 3-D coordinates of the atoms in the molecule (typically several thousand). This information can be abstracted as "cartoons" that show the overall arrangement of the backbone of the peptide chain into elements of secondary structure such as alpha helices or beta sheets (Fig. 2). As beautiful and informative as protein structures are, it is important to be humble about their usefulness. Even in a favorable case where one knows the positions of all the atoms in a protein with high precision (a few hundredths of an Ångstrøm), the structure by itself is only the beginning of an understanding of how the protein works. Yet having a structure, even a low-resolution one, provides a basis for understanding data that would otherwise be difficult to interpret. Using such structures, one can perhaps visualize such phenomena as how substrates dock into the active site of an enzyme, which parts of the protein interact with each other or with other proteins, and which parts of the protein are likely to be floppy.

Proteins are linear polymers of amino acids. There are 20 different kinds of amino acids specified in the genetic code, and the DNA sequence (as determined by genomic projects) specifies the sequence of amino acids that will make up the protein. In turn, the sequence of amino acids determines the 3-D structure of the protein, and the 3-D structure determines the function. Genomic projects are delivering the sequences of a few hundred new proteins every day. One can project that four years from now, we will know the sequences of perhaps 100,000 novel proteins. Determination of the 3-D structures of these proteins is painfully slow by comparison, requiring on average about one man-year of effort by a highly trained scientist at a cost of about $200,000. Tens of thousands of newly-sequenced proteins will nonetheless be attractive targets for pharmaceuticals, agriculture, and chemical manufacturing in the near future. Timely access to their 3-D structures is needed.

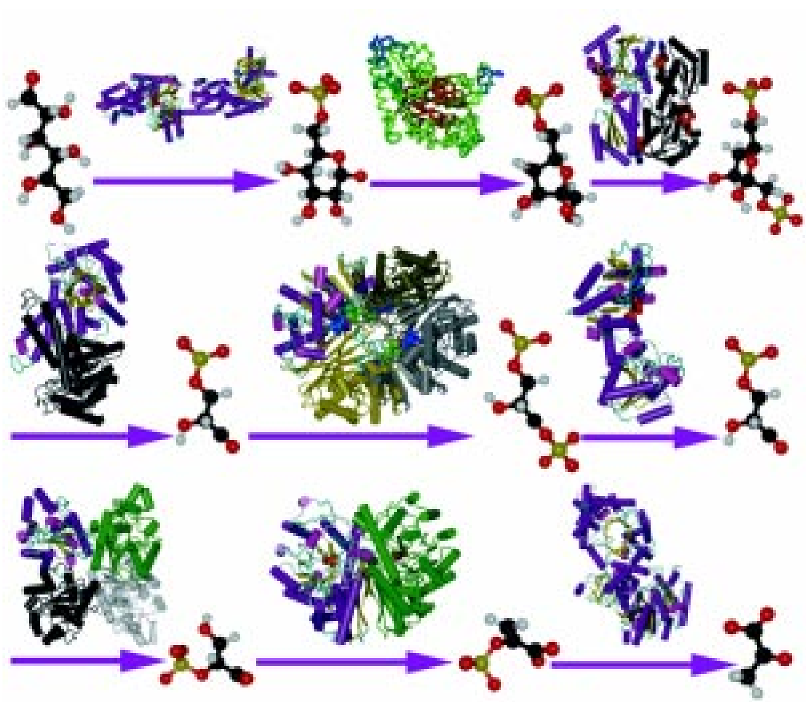


***Fig. 2** Structures enable detailed models of the machinery of life. This figure shows the mechanism of central metabolism, which converts a molecule of glucose into two molecules of pyruvate and stores the energy released as ATP. The cartoons between the molecular models represent the enzymes that carry out the reactions.*

Thus far, researchers have generally appreciated each protein one by one as each structure has been determined, and our understanding of living systems has been crude and incomplete. Currently, however, for well-studied parts of biological systems (such as central metabolism) it is possible to begin building a global and detailed view. If only every pathway in living systems were so well-characterized, how much we might be able to do! After genomic studies pinpointed a protein of interest for medical, chemical, or agricultural applications, then one could use the structural and functional information to move quickly towards a new drug, synthetic process, or disease-resistant plant. It is impossible to conceive of all the uses for such information. Such questions as how genetic variability among patients will affect drug interactions, which at present can only be answered in an approximate way at great expense, might be addressed quickly and accurately through computer simulation if the database that the simulation draws upon is of high enough quality.

Structural Genomics

For the past few years, our team has been working with other structural biologists, genomicists, theorists, and bioinformaticians to determine how best to meet this challenge. A broad consensus has emerged that the structural biology community should mount a large-scale response through an approach called structural genomics. We are encouraged by advances in DNA-sequencing technology developed as part of large-scale genome sequencing projects, and we estimate that a similar large-scale project in structural biology would drive down the time and cost of determining protein structures by an order of magnitude. We believe we should set as our goal the eventual determination of all of the structures of proteins found in nature to an accuracy that is modest at first and improves with time.

The idea behind structural genomics is not simply that the genomes are now available to play with. Nor is it just that there is great potential for improvements in the technology of structure determination and in economies of scale, although those are crucial. Equally important is the idea that through clustering of DNA sequences and 3-D structures, the problem can be divided in a logical way into pieces that research groups can attack and make progress on individually.

Because protein structures fall into families, a structure of one member of the family gives some idea of the structure of the others. How similar the 3-D structures of two proteins will be can be estimated from the similarity of their DNA sequences. At a DNA sequence identity of 25%, for example, the differences in their 3-D sequences can be expected to be about 1 Å rms (root mean square) and the structures will look very similar overall (at the cartoon level). At this level, one could reasonably launch computer modelling efforts to enable drug design, for example. Thus, the structures of the 100,000 proteins thought to be in the human genome could be represented to 1 Å rms by a database of 25,000 structures chosen to give complete coverage at the 25% DNA identity level. If one is willing to start at a much more modest accuracy of 2.5 Å rms (which is accurate enough to assign overall protein fold but not much more), then the number of structures required falls to about 5,000.

To put a scale on the problem, some 500 protein structures have been determined at this level of difference in 40 years of structural biology. Although there has been near-exponential growth in the rate of determination of protein structures, it is clear that to make a serious impact on this problem even at the "fold" level (2.5 Å rms) there will have to be improvements not only in the rate and cost of doing structures, but also in the coordination among research groups in structural biology, bioinformatics, and genomics. At the same time, the traditional focus of structural biology groups on one particular structure determination at a time for a protein of high functional importance will need to be broadened. Any approach that relies heavily on determining one particular protein structure will be prone to getting stuck because that protein may be quite hard to purify or crystallize, while a closely-related structure may be much simpler to determine. Reducing the emphasis on functional importance should permit much faster determination of the structures of one or more members of a broad class of structures.

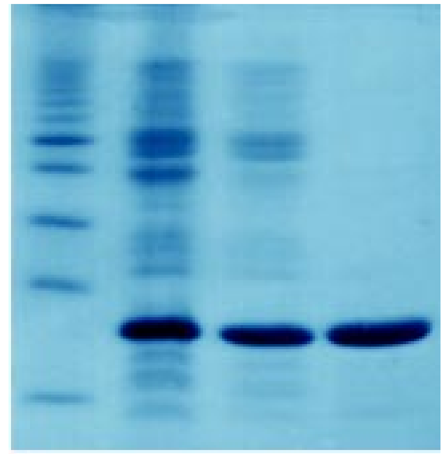


***Fig. 3** Purification of a protein as seen by gel chromatography. The "lanes" of this gel go from low molecular weights (bottom) to high molecular weights (top), with a range of about 40 kDaltons. The lanes from left to right are (1) size standards, (2) crude cell extract from the* **E. coli** *expression host showing a dark band from high expression of the hyperthermophilic target protein, (3) the same extract after centrifugation, and (4) the same extract after heat treatment at 70°C. Most of the host proteins denature and precipitate after heat treatment, but the hyperthermophilic target protein remains.*

A Pilot Project

In January 1998, we set out to explore what would be feasible in a structural genomics project given the current level of technology. We wanted to determine the fraction of the proteins in a particular genome that could be rapidly determined using existing methods, identify the bottlenecks in the process, and develop new technology to overcome the bottlenecks. We began by selecting a model organism, *Pyrobaculum aerophilum* (PA), which is a microbe found in undersea vents at temperatures near 100°C. PA has a significant advantage for our studies because it is a hyperthermophile and a member of the ancient *Thermoprotoreales* order of the *Archaea* branch of the tree of life. Because the hyperthermophile proteins are stable at elevated temperatures and those from *E. coli* (a workhorse organism engineered to produce proteins) are not, one step of purifying our proteins could be a simple heat treatment (see Fig. 3). Proteins from hyperthermophiles are also thought to be more stable even at moderate temperatures, and they may crystallize more readily than proteins from a mesophile. PA's membership in the *Thermoprotoreales* order was an advantage because some classes of proteins (such as DNA-processing proteins) from organisms in this branch of the tree of life have a surprising similarity to proteins from humans. PA was also a good choice because its genomic sequence was already being determined by Jeffrey Miller and his team at the University of California at Los Angeles (UCLA), who were eager to collaborate with us on this project.

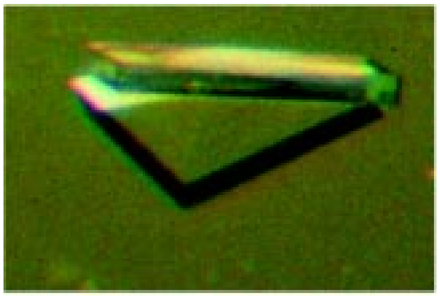


Fig. 4 A protein crystal from **Pyrobaculum aerophilum.** *Protein crystals are typically 30 to 70% water, but nonetheless can diffract to atomic resolution. A single protein crystal will often provide enough x-ray diffraction data to solve the structure and determine the positions of each of thousands of atoms in the asymmetric unit of the unit cell.*

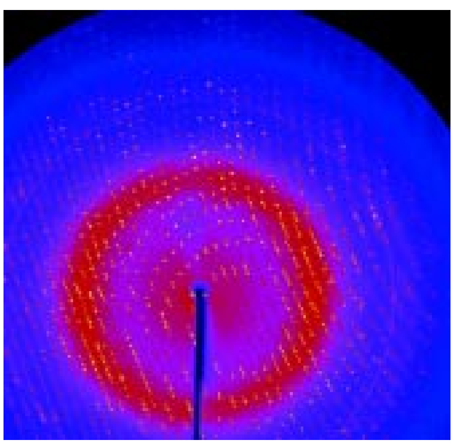


Fig. 5 In a synchrotron x-ray source, electrons are accelerated to energies of several GeV in a polygonal ring with a circumference of about 1 mile. Radiation at the ring's bends (produced by strong magnets) provides an intense x-ray source that is monochromatized and focused on a protein crystal. The crystal is then rotated over 1° in the x-ray beam to produce a diffraction pattern such as this. The intensities of the spots in this pattern are used in calculating an electron density map. Between 60° and 180° of data like this are typically required for a complete data set.

Our first step in answering the feasibility question posed above was to eliminate from consideration any proteins that could be anticipated, based on sequence, to be very difficult to solve. This includes proteins that are too big (800 amino acids), proteins that are associated with membranes, or proteins that lack sufficient methionine residues to apply the crystallographic technique of multiwavelength anomalous dispersion (MAD) on selenium-substituted methionines to solve the crystallographic phase problem.

Based on these criteria, we eliminated 60% of the roughly 2,200 genes in the PA genome from consideration. Then, from the remaining genes, we randomly selected a group of 40 proteins and determined how many could be easily expressed (grown) in a production organisim (*E. coli*). Of the 70% of the proteins that could be easily expressed, 40% of these could be easily purified by the conventional techniques of heat-treatment and His-tag affinity chromatography. These purified proteins were subjected to a conventional crystallization screening procedure, in which 30% formed well-diffracting crystals.

SOLVEing the Structure at X8-C

Once we had a protein crystal (Fig. 4), we determined the structure through data collection at a synchrotron facility (Fig. 5). We shipped pre-frozen crystals to the X8-C x-ray crystallography beamline at the National Synchrotron Light Source (NSLS) at Brookhaven National Laboratory. The NSLS is a facility run by the Los Alamos National Laboratory Biophysics Group (P-21) in collaboration with the Canadian National Research Council, Hoffman-LaRoche Pharmaceuticals, the Brookhaven Biology Department, and the Department of Energy (DOE)-UCLA Laboratory of Structural Biology. Typical data collection times at X8-C, which runs 24 hours per day for roughly 210 days per year, are are a few hours per data set.

Using the data collected at the NSLS, we solved the protein structure using MAD phasing and SOLVE, a software package we developed to increase the rate of structure determination (Fig. 6). SOLVE automates the solution of the “phase problem” of crystallography using MAD or multiple isomorphous replacement data. SOLVE is an expert system that uses advanced statistical methods to automatically solve in a few hours a problem that formerly took days or weeks of a trained crystallographer’s time. SOLVE was recognized as one of the 100 most significant inventions of 1998 by *R&D Magazine*, earning the prestigious R&D100 Award (Fig. 8). Once the complete structure of the protein was determined using SOLVE, we refined the atomic positions to produce a final 3-D model of the protein (Fig. 8). Such models allow us to visualize the overall architecture of the protein, and they are the basis for classifying protein structures into families.

Summary and Outlook

The answer to the question posed by our pilot project is that the cumulative percentage of the proteins in the PA genome that could be rapidly determined using existing methods is roughly 10%. At current productivity levels, we estimate that determining the easiest structures would require one to two man-months of effort per structure.

During the past year, we have played a part in the birth of a new field, structural genomics. As with any infant, it is full of potential but most of the development is still ahead. We anticipate that major national and international projects in structural genomics will be launched by the the DOE, the National Institute of Health, and other agencies, and we expect to form a Joint Proteome Institute with our colleagues at the other national laboratories to coordinate our efforts. New technology will have to be developed if the promise of a comprehensive view of protein structures is to be achieved within the next 15 years. Perhaps most importantly, we will have to make models that reach beyond our immediate findings to more and more distantly related proteins. Filling in the gaps in our knowledge will require experimental, theoretical, and computation efforts that are likely to keep the field in a state of excitement for a long time to come.

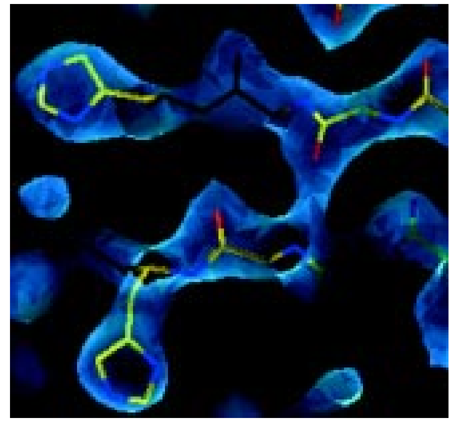


***Fig. 6** An electron density contour map (blue) and an atomic model of that density (yellow, blue, and red sticks). The process of solving the phase problem in producing the electron density map has been automated by SOLVE.*

***Fig. 8** The members of the SOLVE R&D 100 award team, Tom Terwilliger and Joel Berendzen.*

***Fig. 9** Cartoon of a protein structure showing alternating helical and sheet regions and a space-filling representation of an enzymatic substrate at the active site. Such cartoons illustrate the overall architecture of the protein and are the basis for classifying protein structures into families.*

Bayesian Inference Applied to the Electromagnetic Inverse Problem

D. M. Schmidt, J. S. George, and C. C. Wood (P-21)

Introduction

Under suitable conditions of spatial and temporal synchronization, neuronal currents are accompanied by electric potentials and magnetic fields that are sufficiently large to be recorded noninvasively from the surface of the head. Such recordings are known as electroencephalograms (EEGs) and magnetoencephalograms (MEGs), respectively. In contrast to positron emission tomography (PET) and functional magnetic resonance imaging (fMRI), which measure cerebral vascular changes secondary to changes in neuronal activity, EEG and MEG are direct physical measurements of neuronal currents and are capable of resolving temporal patterns of neural activity in the millisecond range.[1,2,3] However, unlike PET and fMRI, the problem of estimating current distribution in the brain from surface EEG and MEG measurements (the so-called electromagnetic inverse problem) is mathematically ill-posed; that is, it has no unique solution in the most general, unconstrained case.[4,5]

To address this difficulty of EEG and MEG, we have developed a new probabilistic approach to the electromagnetic inverse problem[6] based on Bayesian inference (see, *e.g.*, Bernardo and Smith[7] and Gelman, *et al.*[8]). Unlike other approaches to this problem, including other recent applications of Bayesian methods[9,10], our approach does not result in a single "best" solution. Rather, we estimate a probability distribution of solutions upon which all subsequent inferences are based. This distribution provides a means of identifying and estimating the likelihood of current-source features using surface measurements that explicitly emphasize the multiple solutions that can account for any set of surface EEG/MEG measurements.

In addition to emphasizing the inherent probabilistic character of the electromagnetic inverse problem, Bayesian methods provide a formal, quantitative means of incorporating additional relevant information, independent of the EEG/MEG measurements themselves, into the resulting probability distribution of inverse solutions. Such information can include constraints derived from anatomy on the likely location and orientation of current[9,11,12,13], maximum current strength, spatial and temporal smoothness of current, *etc.*

Bayesian Inference

Bayesian inference (BI) is a general procedure for constructing a posterior probability distribution for quantities of interest from the measurements, given prior probability distributions for all of the uncertain parameters—both those that relate the quantities of interest to the measurements and the quantities of interest themselves. The method is conceptually simple, using basic laws of probability. This makes its application even to complicated problems relatively straightforward. The posterior probability distribution is often too complicated to be calculated analytically, but can usually be adequately sampled using modern computer techniques, even in problems with many parameters. More detailed discussions of Bayesian inference can be found elsewhere (*e.g.*, Gelman, *et al.*[8]).

Activity Model

The methods of BI applied to the EEG/MEG inverse problem are demonstrated within the context of a model for the regions of activation. This model is intended to be applicable in evoked-response experiments. There is both theoretical and experimental evidence that EEG and MEG recorded outside the head arise primarily from neocortex, in particular from apical dendrites of pyramidal cells (see, for example, Hämäläinen, *et al.*[1]; Allison, *et al.*[14]; and Dale and Sereno[15]). We therefore construct a model that assumes a variable number of variable-size cortical regions of stimulus-correlated activity in which current may be present. Specifically, an active region is assumed to consist of those locations which are identified as being part of cortex and are located within a sphere of some radius, r, centered on some location, w, also in cortex. There can be any number, n, of these active regions up to some maximum, n_{max}, and the radius can have any value up to some maximum, r_{max}. The goal is to determine the posterior probability values for the set of activity parameters, $\alpha = \{n,w,r\}$, which govern the number, location, and extent of active regions.

Examples

While the methods described apply to models for both EEG and MEG data, the remainder of this research highlight will use MEG data to illustrate the properties of the approach. Both simulated and empirical MEG data for a Neuromag-122 whole-head system were used.[16] The physical setup of the actual MEG experiment was used to determine the location of the subject's head relative to the sensors in the simulated data examples. In addition, an anatomical MRI data set acquired from the subject in the MEG experiment was used to determine the location of cortex (actually gray matter) using MRIVIEW (see Fig. 1), a software tool developed in our laboratory.[17] About 50,000 voxels were tagged, and the normal directions for each of these voxels was then determined by examining the curvature of the local tagged region.

***Fig. 1** Gray matter regions are tagged (in red) from anatomical MRI data. These tagged voxels constitute the anatomical model used to implement the cortical location and orientation prior information.*

In the first example, a simulated data set was generated using the three active regions of different sizes shown in Fig. 2. Normally distributed noise was added to the simulated data at a level typical of empirical experiments. Our Bayesian inference analysis was applied to this data, and ten thousand samples of the posterior probability were generated. A few of these samples are shown in

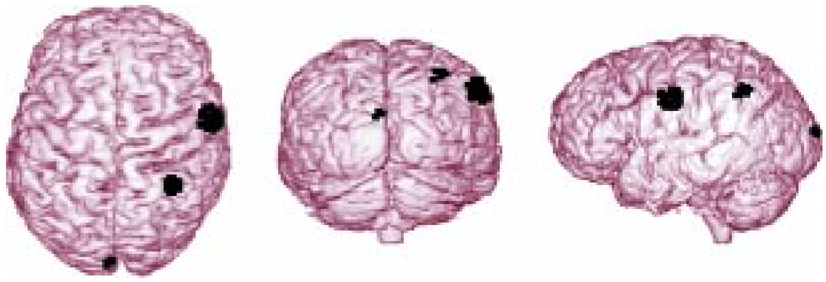


***Fig. 2** Maximum intensity projections of the location and extent of the active regions used to generate the simulated MEG data from the first example.*

Fig. 3. All of the samples shown in Fig. 3 are among the 95% most probable and therefore fit both the data and the prior expectations quite well. Any of these could have produced the given simulated MEG data, yet there are clearly vast differences among the samples. The number of active regions ranges from 3 to 6, the sizes of the regions vary greatly, and the locations of the active regions vary across nearly the entire tagged region of the brain (when considering all samples). This variability is a representation of the degree of the ambiguity of the inverse problem for these MEG data, even with the prior information present.

Despite the degree of variability among the samples in Fig. 3, features common to all are apparent; namely active regions within the three general areas used to generate the simulated data (see Fig. 2). Features such as these, common to all or most of the samples, are associated with a high degree of probability. This

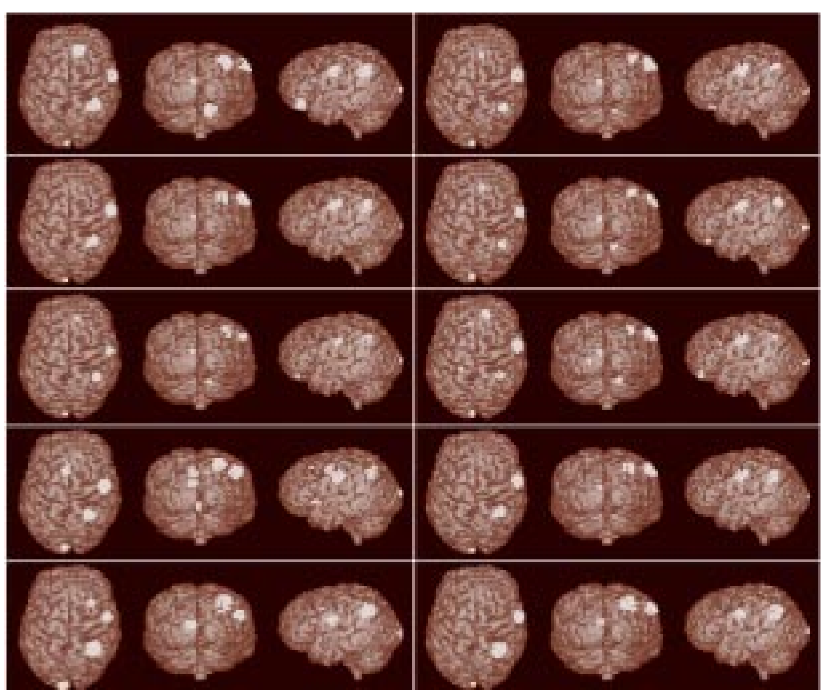


***Fig. 3** A few of the samples drawn from the posterior probability distribution for the simulated data in the first example. Each panel shows three views of the maximum intensity projection of all of the active regions from a single sample. Any of these samples could have produced the given MEG data set.*

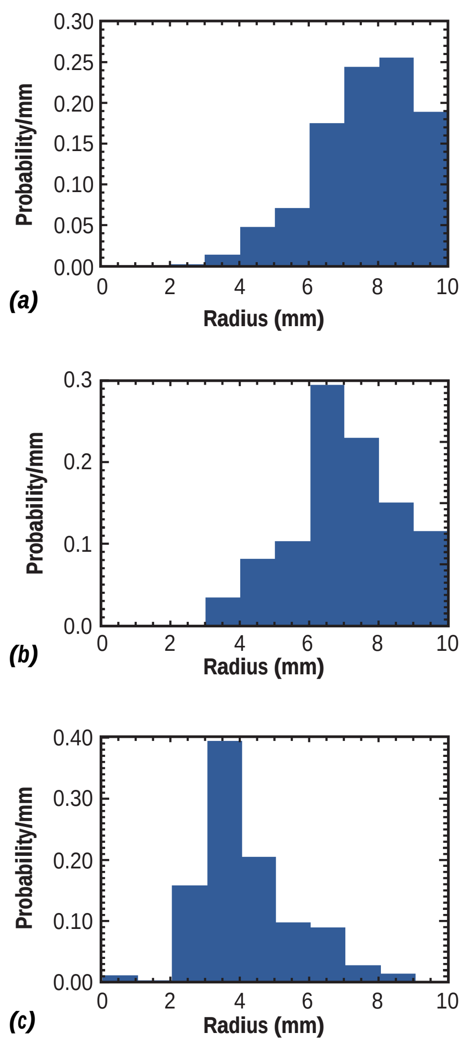
Fig. 4 Three views of the maximum-intensity projections of the location and extent of the three regions found to contain centers of activity at a probability level of at least 95% in the first example.

probability can be quantified because the samples are distributed according to the posterior probability distribution. The smallest sets of voxels that contained the center of the active regions in these three areas across 95% of the samples were identified and are shown in Fig. 4. While these regions are consistent with the locations of the active regions used to generate the simulated data, what is more important is that these regions are consistent with at least 95% of the likely sets of active regions that could also have been generated with this data. This is true even when allowing a variable number of active regions of variable extent. This is a very important feature of BI which is necessarily missing from any other analysis method that only considers one possible result, even if it happens to be the most likely result within a given model.

To learn about the extent and size of each of the active regions localized in Fig. 4, we generated a histogram of the radius of the active regions in each of the areas shown in Fig. 4 across the samples (see Fig. 5). This represents the posterior probability for the size of active regions, assuming there was an active region in each of these areas. The radii of the actual regions used to generate the data were 8, 5, and 3 mm in anterior to posterior order. The agreement between actual radii and posterior probabilities is especially remarkable given the variation in the current strengths of the regions used to generate the data. Such information on extent can be very useful, is not present in most other current methods for analyzing MEG data, and is affirmation of the likely utility of anatomical and physiological prior information.

In our second example, we compared Bayesian analyses of MEG responses to visual stimuli in the left and right visual fields to examine the sensitivity of the Bayesian approach in detecting known features of human visual cortex organization.[18] Based on the crossed anatomical projections of the visual fields to the brain and on previous lesion, MEG, and fMRI studies in humans (see, for example, Horton and Hoyt[19]; Sereno, *et al.*[20]; and Aine, *et al.*[21]), initial cortical activation for stimuli in the left and right visual fields should occur near the calcarine fissure in the occipital region of the contralateral hemispheres.

Fig. 5 The posterior probability distributions for the size of the three active regions whose centers are shown in Fig. 4 in anterior to posterior order. The true sizes of the regions used to generate the simulated data were 8 mm (a), 5 mm (b), and 3 mm (c).



Our Bayesian inference analysis was applied separately to the data for each visual field stimulus at 110-ms post-stimulus latency, a latency that should include robust activation of the calcarine region.[21] Regions that contained activity at a probability of 95% were identified and are shown in Fig. 6. This figure depicts relative probability of activation within these regions on a color scale in three orthogonal slices through the calcarine region and a three-dimensional (3-D) rendering of the occipital region. For the left visual field stimulus, maximal probability of activation at 110 ms was located in the right (contralateral) hemisphere, centered on the calcarine region. This pattern was reversed for the right visual field stimulus at 110 ms, consistent with the predictions from anatomy and from the lesion, fMRI, and previous MEG studies cited above.

Two additional features of the results in this second example should be noted. First, although maximal probability of activation at 110-ms latency was indeed located in the opposite hemisphere, there exists sizable probability for activity in the ipsilateral hemisphere near the mid-line. The extent of the 95% probability regions shown in Fig. 6 is indicative of both the extent of estimated activation and the degree of error or uncertainty in that estimate, even allowing for the possibility of different numbers of active regions of variable extent. Second, although not shown in detail here, analyses at other latencies suggest a progressively increasing number of probable regions of activation in both the ipsilateral and contralateral hemispheres over the latency region from 110 to 160 ms following stimulus onset. It will be of considerable interest to explore the time dependence of the Bayesian inference analyses in relation to evidence for multiple, functionally organized areas of striate and extra-striate visual cortex and to examine the value of temporal prior information (not included in the current activation model) in the form of, for example, temporal covariance constraints.

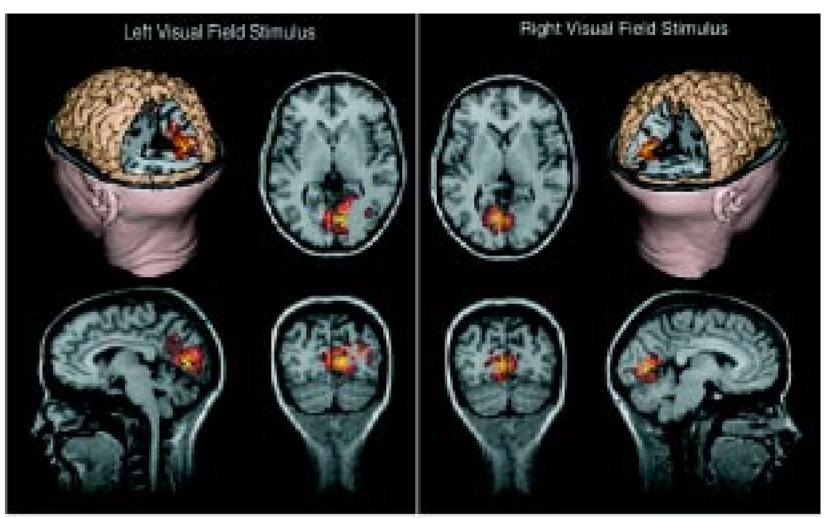


***Fig. 6** Four views of a region found to contain activity at a 95% probability level in the second example for both left and right visual field stimuli at 110-ms latency. The two-dimensional views show the regions within the anatomical MRI data using a temperature-like color scale (bright yellow represents the highest probability). The 3-D views show the locations of the regions relative to other brain structures. These results indicate that the highest probability of activity is in the calcarine region of the hemisphere contralateral to the visual field stimulated.*

In addition, the Bayesian approach provides a natural means for incorporating information from other functional imaging modalities such as PET or fMRI.[12,13,22] The latter can be readily achieved with the Bayesian framework and with this activity model by assigning prior probabilities to possible locations of active regions based on results from the other modality or modalities. Such a Bayesian formulation of multimodality integration would yield an inherently probabilistic result in which the quantity estimated would be the probability of activation as a function of both space and time.

References

[1] M. Hämäläinen, R. Hari, R. J. Ilmoniemi, J. Knuutila, and O. V. Lounasmaa, "Magnetoencephalography—Theory, Instrumentation, and Applications to Noninvasive Studies of the Working Human Brain," *Review of Modern Physics* 65, 413 (1993).

[2] C. J. Aine, "A Conceptual Overview and Critique of Functional Neuroimaging Techniques in Humans: MRI/fMRI and PET," *Critical Reviews in Neurobiology* **9**, 229 (1995).

[3] A. W. Toga and J. C. Mazziotta, *Brain Mapping: The Methods* (Academic Press, New York, 1996).

[4] H. von Helmholtz, "Ueber einige gesetze der vertheilung elektrischer strome in korperlichen leitern, mit anwendung auf die thierisch-elektrischen versuche," *Annalen der Physik und Chemie* 89, 211 and 353 (1853).

[5] P. Nunez, *Electrical Fields of the Brain: Neurophysics of the EEG* (Oxford University Press, Oxford, 1981).

[6] D. M. Schmidt, J. S. George, and C. C. Wood, "Bayesian Inference Applied to the Electromagnetic Inverse Problem," Los Alamos National Laboratory report LA-UR-97-4813 (1997). To be published in *Human Brain Mapping*.

[7] J. M. Bernardo and A. F. M. Smith, *Bayesian Theory* (Wiley, New York, 1994).

[8] A. Gelman, J. B. Carlin, H. S. Stern, and D. B. Rubin, *Bayesian Data Analysis* (Chapman & Hall, London, 1995).

[9] S. Baillet and L. Garnero, "A Bayesian Approach to Introducing Anatomo-Functional Priors in the EEG/MEG Inverse Problem," *IEEE Transactions on Biomedical Engineering* 44, 374 (1997).

[10] J. W. Phillips, R. M. Leahy, and J. C. Mosher, "MEG-Based Imaging of Focal Neuronal Current Sources," *IEEE Transactions on Medical Imaging* 16, 338 (1997).

[11] J. Z. Wang, S. J. Williamson, and L. Kaufman, "Magnetic Source Images Determined by a Lead-Field Analysis: the Unique Minimum-Norm," *IEEE Transactions on Biomedical Engineering* 39, 665 (1992).

[12] J. S. George, C. J. Aine, J. C. Mosher, D. M. Schmidt, D. M. Ranken, H. A. Schlitt, C. C. Wood, J. D. Lewine, J. A. Sanders, and J. W. Belliveau, "Mapping Function in the Human Brain with MEG, Anatomical MRI, and Functional MRI," *Journal of Clinical Neurophysics* 12, 406 (1995).

[13] A. M. Dale, "Strategies and Limitations in Integrating Brain Imaging and Electromagnetic Recording" *Society for Neuroscience Abstracts* 23, 1 (1997).

[14] T. Allison, C. C. Wood, and G. McCarthy, "The Central Nervous System," in *Psychophysiology: Systems, Processes and Applications: A Handbook*, E. Donchin, S. Porges, and M. Coles, Eds. (Guilford Press, New York, 1986), pp. 5–25.

[15] A. M. Dale and M. I. Sereno, "Improved Localization of Cortical Activity by Combining EEG and MEG with MRI Cortical Surface Reconstruction: a Linear Approach," *Journal of Cognitive Neuroscience* 5, 162 (1993).

[16] A. I. Ahonen, M. S. Hämäläinen, M. J. Kajola, J. E. T. Knuutila, P. P. Laine, O. V. Lounasmaa, L. T. Parkkonen, J. T. Simola, and C. D. Tesche, "122-Channel SQUID Instrument for Investigating the Magnetic Signals from the Human Brain," *Physica Scripta* T49A, 198 (1993).

[17] D. M. Ranken and J. S. George, "MRIVIEW: An Interactive Computational Tool for Investigation of Brain Structure and Function," in *Visualization '93* (IEEE Computer Society, 1993), pp. 324–331.

[18] C. Aine, H. W. Chen, D. Ranken, J. Mosher, E. Best, J. George, J. Lewine, and K. Paulson, "An Examination of Chromatic/Achromatic Stimuli Presented to Central/Peripheral Visual Fields: An MEG Study," *Neuroimage* 5, 153 (1997).

[19] J. C. Horton and W. F. Hoyt, "The Representation of the Visual Field in Human Striate Cortex," *Proceedings of the Royal Society of London* 132, 348 (1991).

[20] M. I. Sereno, A. M. Dale, J. B. Reppas, K. K. Kwong, J. W. Belliveau, T. J. Brady, B. R. Rosen, and R. B. H. Tootell, "Borders of Multiple Visual Areas in Human Revealed by Functional Magnetic Resonance Imaging," *Science* 268, 889 (1995).

[21] C. Aine, S. Supek, J. George, D. Ranken, J. Lewine, J. Sanders, E. Best, W. Tiee, E. Flynn, and C. C. Wood, "Retinotopic Organization of Human Visual Cortex: Departures from the Classical Model," *Cerebral Cortex* 6, 354 (1996).

[22] J. Belliveau, "Dynamic Human Brain Mapping using Combined fMRI, EEG and MEG," Symposium on Approaches to Cognitive Neuroscience by Means of Functional Brain Imaging (Caen, France, 1997).

Design and Preliminary Results from a High-Temperature SQUID Microscope for Nondestructive Evaluation

M. A. Espy, L. Atencio, A. Matlashov, and R. H. Kraus, Jr. (P-21)

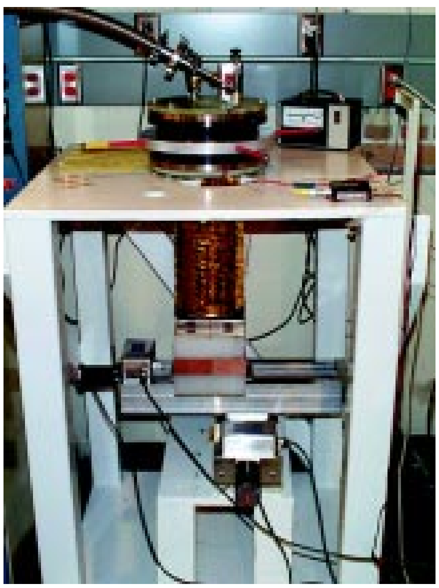


Fig. 1 Photograph of the SQUID microscope dewar operating in our laboratory.

The superconducting quantum interference device (SQUID) is the most sensitive detector of magnetic fields known. SQUIDs are so sensitive that they are able to detect magnetic fields ten billion times smaller than Earth's. Because of their incredible sensitivity, SQUIDs can be used to detect the minute magnetic fields associated with biological function, such as the magnetic fields present outside the head due to neuronal activity in the brain. The primary objective of our work has been developing biological applications for SQUID measurements, such as magnetic mapping of brain function. In addition, we have applied SQUID sensor measurement and analytic approaches to the problem of nondestructive evaluation of stockpile weapons components as part of Los Alamos National Laboratory's Enhanced Surveillance Program, a component of the Department of Energy's (DOE's) science-based stockpile stewardship (SBSS) program.

We have designed a SQUID "microscope" that uses a liquid-nitrogen-cooled SQUID sensor to map magnetic fields induced in a sample (Fig. 1). Similar instruments are described by Black[1]; Kirtley, *et al.*[2]; and Cochran, *et al.*[3]. Our microscope characterizes the features of interest in the sample (*e.g.*, defects due to aging) by detecting anomalies in the induced magnetic field. To address the needs of SBSS, we designed an instrument that is sensitive to small features buried under several intervening layers (~1–20 mm) of conducting and/or nonconducting materials, and that is robust enough to operate even in magnetically noisy, unshielded environments. Our microscope, which has been operational since September 1997, has primarily been applied to specific nondestructive evaluation problems such as detecting and determining the width of buried "seams" inside nuclear components without having to take the components apart. This research highlight describes how the microscope works, and it presents the results of several tests that demonstrate the usefulness of this technology.

Compared with other technologies, SQUIDs are well suited to many problems of buried features such as cracks, pits, or other structural abnormalities. A technique such as complex impedance measurement has to go to lower drive frequencies, ω, to get the required skin depth, δ (the distance that the eddy currents penetrate into the material before falling to ~37% of their magnitude at the surface). As shown in the equations below, the lower the frequency the greater the skin depth (and the more deeply one can probe for a defect). However, lower frequencies also result in a corresponding decrease in signal strength, V, as shown:

$$\delta = \sqrt{\frac{2\rho}{\omega\mu_0}} \quad and \quad V \propto \omega,$$

where ρ is the resisitivity of the material. Ultrasound, on the other hand, has difficulties with signal reflection at the boundaries of material layers that are sonic absorbers (most plastics and electrical insulators), reducing the sensitivity to features below such layers. Finally, radiographic techniques can be expensive, nonportable, and insensitive to small one-dimensional features. SQUIDs are not limited by these shortcomings. SQUID sensitivity does not depend on frequency, enabling these sensors to be used for detecting features and defects over a broad range of material depths. The induction signal at a given frequency depends only on ρ, not on gaps or intervening layers. Also, a SQUID system can be portable and relatively inexpensive.

Figure 2 is a schematic diagram of the SQUID microscope and the data acquisition system. The main component of the microscope is the dewar, which is shown mounted in a wooden stand in Fig. 1. The inner chamber of the dewar is filled with liquid nitrogen. The high-temperature superconducting SQUID, a bare Conductus "Mr. SQUID"™ chip with an area of 30×30 μm and a sensitivity of 700 nT/Φ_0, is located in vacuum on the tip of a sapphire cold-finger, which is in contact with the liquid nitrogen reservoir. A 1-cm-diameter, 0.25-mm-thin quartz window is mounted on the bottom of the dewar immediately below the SQUID. During operation, the SQUID is located ~0.13 mm from the window. The cold-finger keeps the SQUID at ~78°K despite its proximity to the outside world (~300°K). The small area of the SQUID allows the instrument to operate without shielding in the magnetically noisy environment of our laboratory. Eventually, a second SQUID will be installed at the base of the sapphire cold-finger to construct a first-order gradiometer.[4,5]

The eddy-current induction coils, used to induce a magnetic field in the sample, are located on the outside of the dewar just beneath the window. The induction coils were designed to produce a "null" in the magnetic field at the location of the SQUID, thus using little or no sensor dynamic range for the induction signal. Two designs have been used thus far. The first consisted of two pairs of "double-D" coils rotated by 90°. In this design, the large size of the double-D coils relative to the sample sizes produced asymmetric eddy-currents at the sample edges resulting in large anomalous signals. We were able to avoid most of these edge effects by using the second design, a circle-within-rectangle coil, which is shown in Fig. 2. Two adjustable current generators with 150-mA maximum output current, driven by a common function generator, provide current to the two induction coils. The function generator also provides a reference signal to the lock-in amplifier.

Prior to data acquisition, the sample is centered on the two-axis scanning stage located below the dewar. The distance between the SQUID and the top of the sample is typically 1 mm. The current in the induction coils is adjusted until the SQUID measures a minimum magnetic field. During data acquisition, a personal computer controls the SQUID electronics (Conductus pcSQUID™ electronics) and the motion control system. Low-magnetic-noise stepper motors move the sample, and the SQUID electronics provide the SQUID's response amplitude and phase to the lock-in amplifier. At each point, the personal computer reads the lock-in amplifier, which provides data based on the amplitude and phase of the SQUID responses relative to the reference signal.

Initial data were taken using 150- × 150- × 1.5-mm-thick aluminum plates. Blank plates (unperturbed rolled-stock) and flawed plates (with induced cracks and holes) were examined both individually and

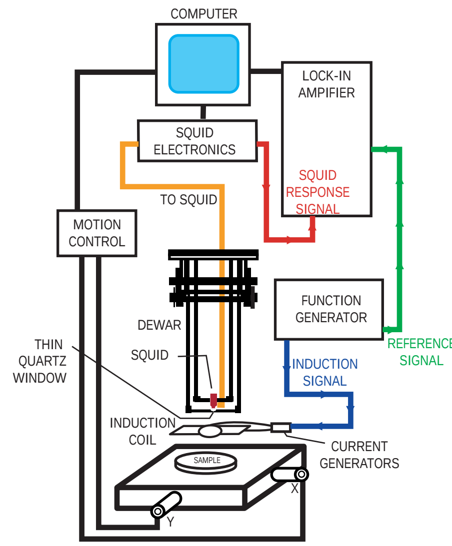


***Fig. 2** Schematic drawing of the SQUID microscope and data acquisition system.*

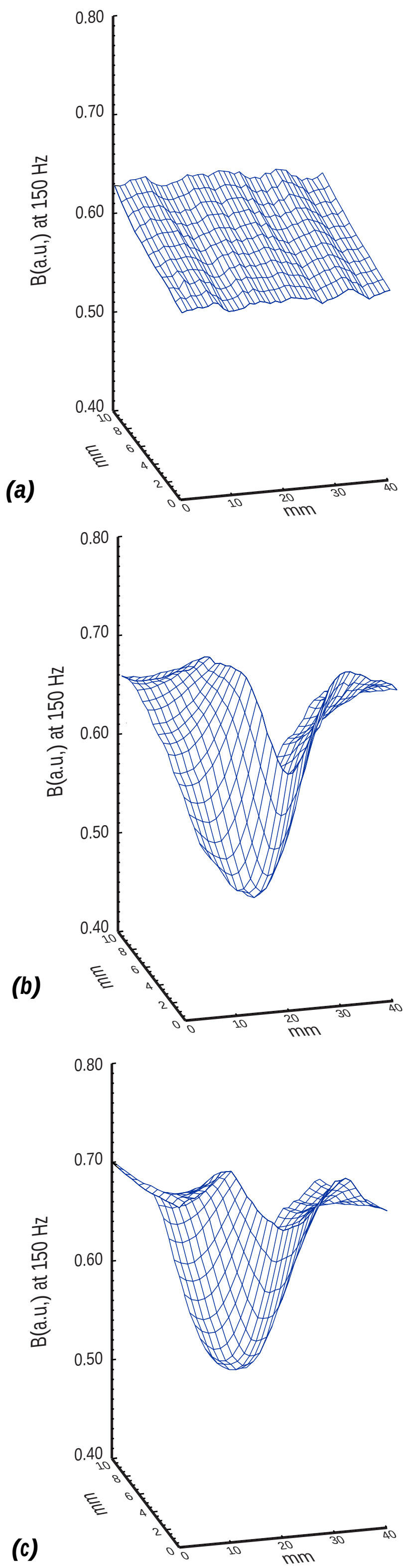


Fig. 3 Scan of a blank aluminum plate (a), cracked aluminum plate (b), and cracked aluminum plate covered by an unflawed plate (c). Induction frequency was 150 Hz.

stacked. Figure 3 plots the raw amplitude from the lock-in amplifier as a function of position for an unflawed aluminum plate (a), a plate with a crack (b), and a plate with a crack all the way through the 1.5-mm plate material covered by an unflawed plate (c). The presence of the crack is indicated by a valley in which the width of the valley is proportional to the width of the crack. Figure 4 presents raw data for an aluminum plate with holes of various diameters. The presence of a hole is indicated by a two-lobed signal in which the spacing between the lobes is proportional to the diameter of the hole. (The spikes in the data occur where the SQUID electronics momentarily unlocked.) Even 1-mm-diameter holes are visible. Data were also collected for this same plate covered by an unflawed plate (not shown), and all of the holes were still visible (background subtraction was applied to resolve the smallest two holes).

Following these initial data, we analyzed a titanium-tungsten sample that had a stress fracture. A photograph of this sample is shown in Fig. 5a. The results of a single-pass scan lengthwise over the sample are shown in Figure 5b. This sample was slightly ferromagnetic, which poses a challenge to an instrument as sensitive as a SQUID. Simply moving a slightly magnetic object beneath a SQUID can be enough to overwhelm the instrument. However, because of the small SQUID pick-up coil on this device, we were still able to make the scan. This suggests that the instrument should be flexible enough to handle “real-world” objects that might also be slightly magnetized. The stress fracture was clearly observed, demonstrating sensitivity to severe lattice defects that do not necessarily evidence a physical separation. This data set illustrates that while the instrument can localize defects on the submillimeter scale, it is sensitive to defects that are orders of magnitude smaller. It is also interesting to note that the chamfer at the left edge of the sample shown in Fig. 5a is visible in the scan at 633 Hz.

To further test the capabilities of our microscope, we analyzed flaws in fiberglass plates coated with 100 µm of copper. For one of these plates, we carved the initials “P-21” through the copper to expose the fiberglass beneath. This sample is shown in Fig. 6a. Figure 6b shows the raw data from a scan of this plate. The letters are clearly visible.

In another set of these plates (not shown), we carved closely spaced pairs of scratches. The scratches were ~100-µm wide, 75-mm long, and penetrated the 100-µm copper layer. The scratch pairs were separated by different distances. The scratches that were 5 mm apart were resolved. The scratch-pairs that were 3-mm and 1-mm apart each appeared as one scratch, although the 3-mm scratch-pair was wider. These data indicate the need to design induction coils tailored to the specific type of defect being sought. Improved induction coil design and the use of a SQUID array will ultimately provide the highest resolution.

To specifically address the SBSS problem of quantitatively monitoring the evolution of known seams in nuclear components over time, we designed a simple test sample using two 150- × 150- × 10-mm-thick titanium plates. Titanium was chosen because it has conductivity similar to the specific materials of interest.

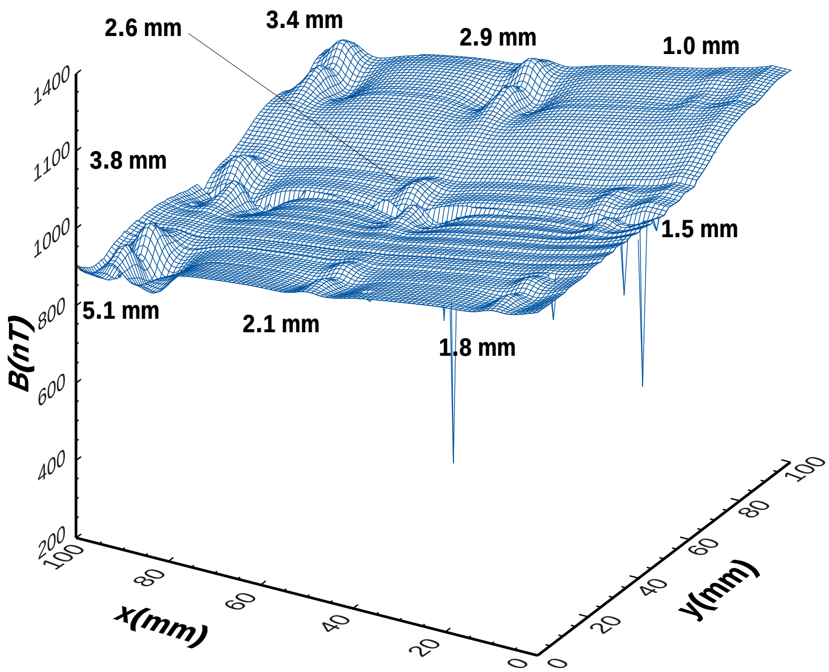
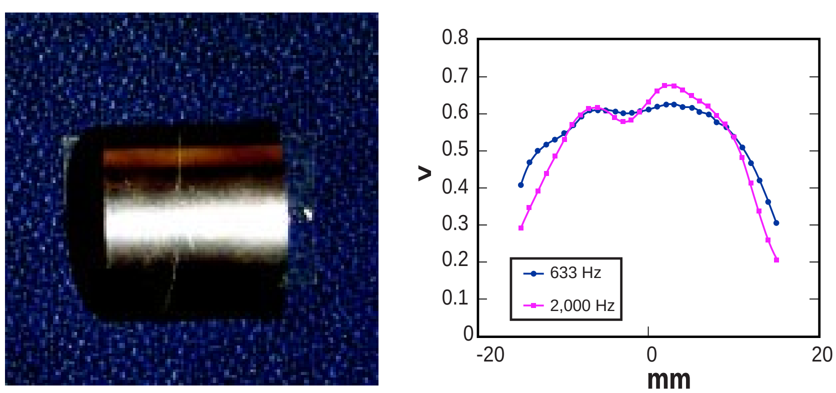
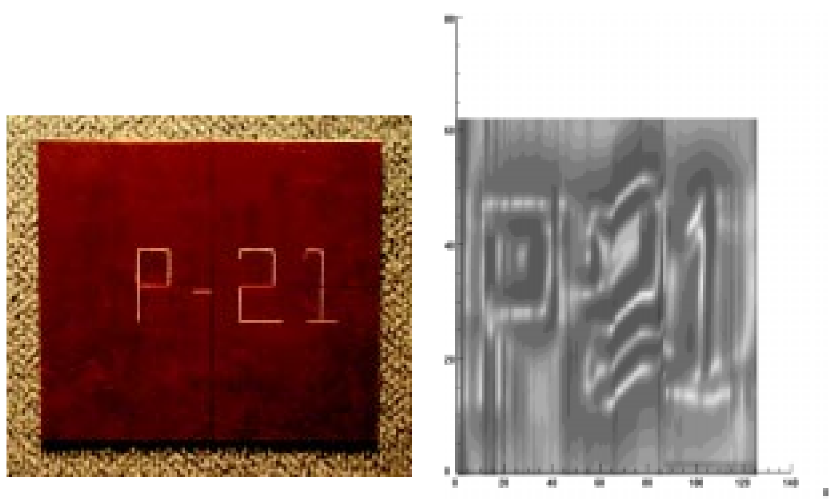


***Fig. 4** Raw data for aluminum plate with holes of various diameters. Induction frequency was ~300 Hz.*



(a) *(b)*

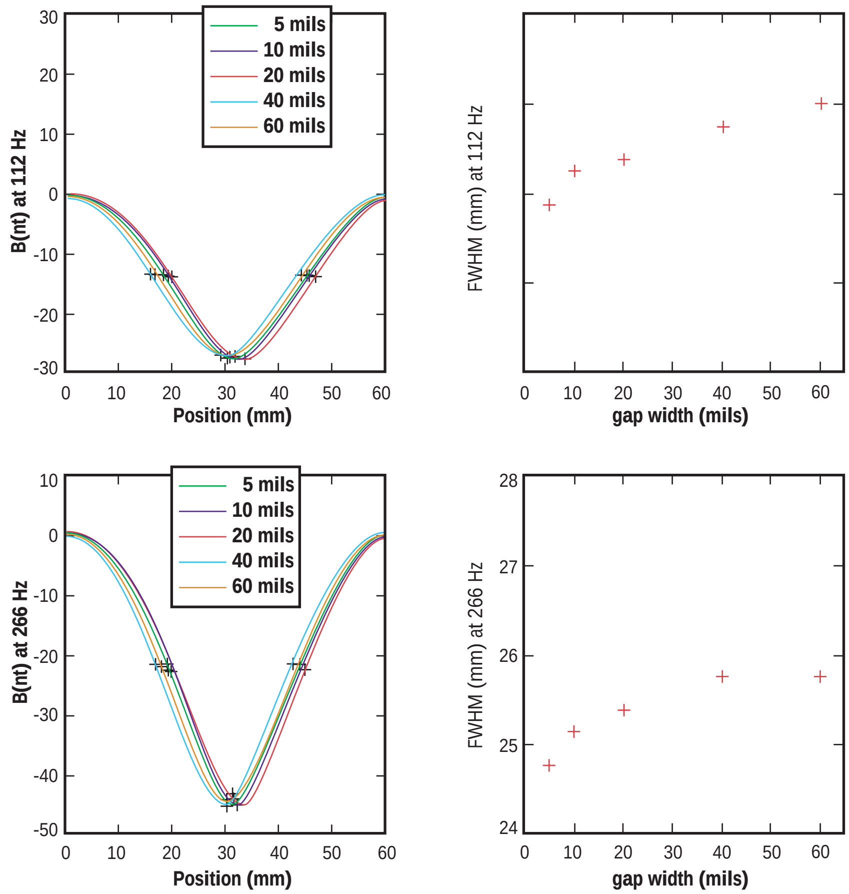
***Fig. 5** (a) Photograph of titanium-tungsten surrogate with a stress fracture. (b) Data from a single scan lengthwise down the surrogate.*



(a) *(b)*

***Fig. 6** (a) Photograph of 150- × 150-mm copper-plated fiberglass plate with "P-21" scratched into the 100-μm-thick copper layer. (b) Raw data from a scan of this plate.*

Fig. 7 Data for seams of various widths in a titanium plate at 112 Hz and 266 Hz. The seams were buried under 1 cm of unflawed plate.



A seam was simulated by cutting one of the plates in half and inserting spacers. In real SBSS cases, seams are typically buried under ~1 cm of conducting material, making it very challenging to determine whether they are changing width as they age. To simulate such a case, the second unflawed titanium plate was stacked on top of the “seamed” plate.

Our goal was to obtain quantitative information about the width of the buried seam. Scans were taken for seam widths of 5, 10, 20, 40, and 60 mils at 112-Hz and 266-Hz induction frequencies. Results are presented in Fig. 7. The response to the seam appears as a valley in the data. The full-width-at-half-minimum (FWHM), or the width of the valley when its height is at half its minimum value, was fit for each scan and is plotted as a function of seam width. As expected, the amplitude of the response grows with frequency. The lower frequency (112 Hz) appears to show the trend of FWHM versus seam width most clearly. This is also somewhat expected; at 112 Hz the skin depth is 2.2 cm (recall that the seam is 1 cm beneath a titanium plate) while the skin depth for 266 Hz is 1.4 cm. Another interesting feature of the data is that at both 112 Hz and 266 Hz the curve of FWHM as a function of seam width appears to be leveling off. One possible explanation is that the response should fall off as the seam width increases beyond the “field of view” of the SQUID.

We have begun modeling the titanium seam width problem using OPERA, a commercial electromagnetic finite-element code developed by Vector Fields, Inc. We anticipate that the results of this modeling effort will enable us to design new induction coils sensitive to specific features of interest at particular depths in a sample. In addition, we have fabricated a series of copper calibration plates with 75-mm-long scratches of depths and widths ranging from 0.125 to 1 mm. We intend to use data taken with these plates in conjunction with the model to further quantify the resolution of the instrument and the competing effects of depth and width of buried seams.

We are also pursuing a number of other improvements to our technique. In collaboration with Oak Ridge National Laboratory, a five-axis motion control system with low magnetic noise is being developed that will enable us to examine spherical and cylindrical samples. In addition, collaborators at Allied Signal/Kansas City Plant are currently developing flux-locked loop electronics with high slew-rate to improve operations in electromagnetically noisy environments. We are also designing a SQUID-array to enhance the resolution of the instrument. While our results are already promising, these improvements will ensure that the SQUID microscope offers useful, accurate results for SBSS and other applications.

References

[1] R. C. Black, "Magnetic Microscopy using a Superconducting Quantum Interference Device," Ph.D. thesis, University of Maryland (1995).

[2] J. R. Kirtley, M. B. Ketchen, C. C. Tsuei, J. Z. Sun, W. J. Gallagher, L. S. Yujahnes, A. Gupta, K. G. Stawiasz, and S. J. Wind, "Design and Applications of a Scanning SQUID Microscope," *IBM Journal of Research and Development* 39, 655 (1995).

[3] A. Cochran, J. Kuznik, C. Carr, L. N. C. Morgan, and G. B. Donaldson, "Experimental Results in Nondestructive Evaluation with High Temperature Superconducting SQUIDs," *Institute of Physics Conference Series* 148, 1511 (1995).

[4] M. A. Espy, R. H. Kraus, Jr., E. R. Flynn, and A. Matlashov, "Two Methods for a First Order Hardware Gradiometer using Two High Temperature Superconducting Quantum Interference Devices," *Review of Scientific Instruments* 69, 123 (1998).

[5] Y. Tavrin, H. J. Krause, W. Wolf, V. Glyantsev, J. Schubert, W. Zander, A. Haller, and H. Bousack, "Eddy-Current Technique with High Temperature Superconducting SQUID Gradiometer for Nondestructive Evaluation of Nonmagnetic Metallic Structures," *Institute of Physics Conference Series* 148, 1519 (1995).

CYRAX™: A Portable Three-Dimensional Laser-Mapping and Imaging System

K. Wilson, C. Smith, and D. Neagley (P-21); B. Kacyra and J. Dimsdale (Cyra Technologies); and J. J. Zayhowski (MIT Lincoln Laboratory)

***Fig. 1** The Cyrax laser-mapping and imaging system stands about 4-ft tall and can be easily set up and operated by a single user.*

Introduction

More than 60 percent of the construction done today is either renovation or expansion work as more owners focus on extending the lives of existing facilities. To plan for expansions and renovations, owners rely heavily on accurate computer aided design (CAD) models of the as-built condition of their facilities. CAD models require considerable investment to ensure that they are updated as the facility is modified. Using conventional methods to create or update models is slow, costly, and often impossible. To meet the need for a quicker, cost-effective way to create accurate three-dimensional (3-D) models, we have developed Cyrax, a portable system for acquiring 3-D data and generating 3-D models of large, complex structures.

Cyrax, shown in Fig. 1, is a completely integrated laser radar and 3-D modeling system that produces a digital model, like that of a digital camera but with added range information that provides the accurate 3-D geometry of the scanned structure. Cyrax eliminates the human error inherent in labor-intensive digitization processes like photogrammetry (in which large numbers of photographs must be taken, scanned, and tiled by hand) by automatically gathering and processing data on the entire structure. Using this stored data, accurate 3-D CAD models of any portion of the scanned structure can be produced at about one-fourth the cost. Cyrax's system provides greater range with a powerful eye-safe laser and greater time resolution. Cyrax is therefore the only technology that can collect accurate 3-D data and create 3-D digital representations and models of large objects such as oil refineries, buildings, mines, and ships.

Development of Cyrax was a joint effort between Cyra Technologies, Los Alamos National Laboratory, and the Massachusetts Institute of Technology (MIT) Lincoln Laboratory. Researchers from the Los Alamos Physics Division developed the time-interval interpolator integrated circuit, a precise time-measuring innovation that makes Cyrax possible. Cyra Technologies was responsible for developing the computer graphics perception (CGP) operating software and CAD software and integrating them with the laser and other mechanical hardware. MIT Lincoln Laboratory developed Cyrax's laser, which generates a 200-ps light pulse that is used with the time-interval interpolator to measure the two-way optical time of flight between Cyrax and an object. The success of this research and development (R&D) collaboration earned Cyrax an R&D 100 Award from *R&D Magazine* as one of the 1998's best innovations (Fig. 2).

Time Interval Interpolator Technology

The time-interval interpolator integrated circuit (Fig. 3) is a technologically significant component in Cyrax. This timing circuit marks the laser firing time and measures the return time of the laser pulse. It is the high speed of the integrated circuit that allows Cyrax to obtain accurate 3-D data at high rates. The time-interval interpolator integrated circuit used in Cyrax is the culmination of more than eight years of research. The original aim of this research was to meet time-measurement needs of the Los Alamos nuclear weapons program, but the end result is a technology that offers time-measurement solutions for a much wider range of applications.

Before the moratorium on underground nuclear testing, researchers in the nuclear weapons program measured the time history of fast neutron growth rate as an important diagnostic tool during experiments at the Nevada Test Site. The many decades of neutron growth that occur in a very short time during a nuclear event are expressed by the following equations:

$$n(t) = n_0 e^{\int_{t_0}^{t} \alpha(t)dt}$$

and then,

$$\alpha(t) = \frac{n'(t)}{n(t)} = \frac{d}{d(t)} \log_e(n[t])$$

where n = number of neutrons, t = time, and α = neutron growth rate.

Historically, the many decades of neutron growth were measured using a series of oscilloscopes that each captured an instantaneous waveform measurement as the experiment progressed. For several decades, this labor-intensive method remained relatively unchanged from Bruno Rossi’s first measurements during the Trinity experiment. In the mid-1980s, a better method was conceived that would replace the oscilloscope measurements with measurements of the times at which the growth curve crosses fixed voltages. This method automated the measurement, eliminating the labor costs of the old process.

To make such measurements possible, we developed a high-resolution time interval meter (TIM) (U.S. Patent 5,030,850) based on hybrid circuits and designed for use in high-bandwidth waveform digitizers for the precision monitoring of ultrafast electrical pulses. The waveform recorders built with these circuits proved to be very effective, achieving or exceeding the accuracy of the more labor-intensive method, but they were huge ($10 \times 6 \times 3$ ft), consumed too much power, and generated too much heat. To address these practical problems, we incorporated several technical breakthroughs that allowed us to replace the hybrid-circuit design with a low-cost, low-power, stable integrated-circuit chip without compromising performance. This Los Alamos custom chip, completed in 1994, offers a compact technology that reliably, accurately, and inexpensively makes real-time measurements at picosecond time scales. This chip opened the doors for a wide range of applications, not only for basic research, but also for innovative technologies like Cyrax that depend on that fundamental parameter of all science and technology: time.

***Fig. 2** Physics Division scientists Kerry Wilson, Dan Neagley, and Clayton Smith developed the time-interval interpolator integrated circuit that gives Cyrax its accuracy and speed. Their collaboration with Cyra Technologies and MIT Lincoln Laboratory earned an R&D 100 Award in 1998.*

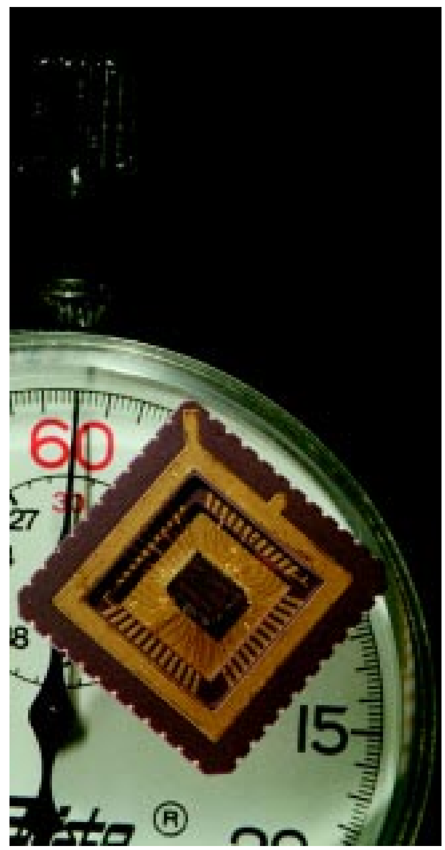


***Fig. 3.** The time-interval interpolator integrated circuit, shown with a stopwatch, provides precision timing for Cyrax and other applications. Much as a stopwatch dial divides each minute into 60 second interpolations of the hand's revolution speed, this integrated circuit subdivides a 100-MHz crystal clock’s 10-ns cycle into 1,000 subintervals for 10-ps resolution.*

(a)

(b)

(c)

(d)

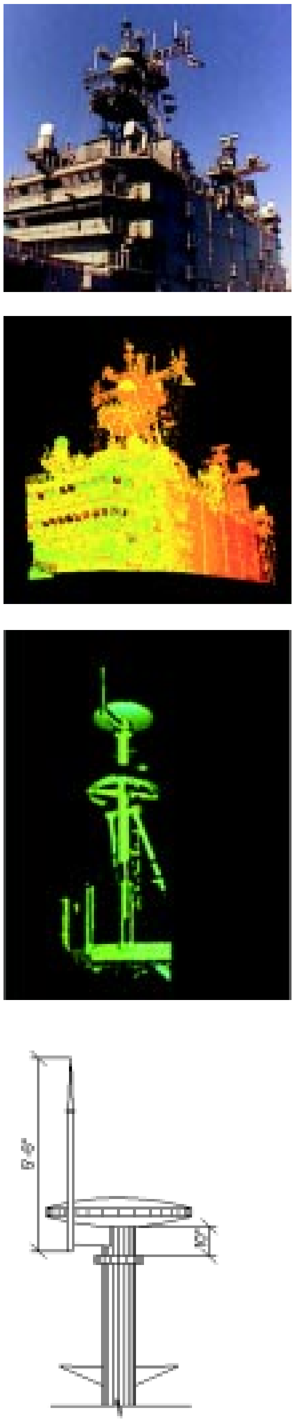


Fig. 4 In a pilot study for the U.S. Navy, Cyrax scanned the U.S.S. Tarawa's island superstructure ***(a)****. The associated software instantaneously created a* ***3-D*** *digital representation* ***(b)*** *that was viewed on a laptop computer as scanning occurred. The data for the ship's mast were then converted into a* ***3-D*** *surface model* ***(c)****, which was exported to a* ***CAD*** *application to create an accurate, detailed* ***2-D*** *drawing* ***(d)****.*

How Cyrax Works

Cyrax contains three primary components. The first is the field digital vision (FDV) machine, which collects the data used to image the structure. The FDV machine comprises a "laser radar" transceiver, an electromechanical scanner, an embedded computer and video camera, and associated electronics, including the time-interval interpolator integrated circuit. The second component is the CGP software application, which runs on a laptop computer to provide FDV control, dynamic visualization, modeling, and interactive 3-D editing. The third component is the software for converting 3-D data to commonly used CAD applications, such as AutoCAD and MicroStation.

Cyrax is simple enough to be operated by one person. The operator sets up the portable, tripod-mounted FDV in front of the object to be scanned. The laser has a 40° field of view and can scan objects from as far away as 100 m without loss of accuracy. The object is displayed by the video display and CGP software on a laptop computer's screen. The operator selects the region of interest and the amount of detail to be scanned by the FDV, and the FDV sends out green, passively Q-switched laser pulses (U.S. Patent 5,394,413) that scan the object as a "cloud of points." This cloud of points is a collection of mathematical points—in x, y, and z space—that represents the actual object's surface in three dimensions. The FDV determines the location of a particular point by measuring the time it takes for a light pulse to travel from the FDV laser to the surface point and back to the FDV light detector. The time interval interpolator integrated circuit measures this time interval to a precision of 10 ps and thus allows locations to be measured to a precision of 2 mm. (This time resolution and accuracy can be characterized from the TIM's own clock frequency and confirmed by the physical dimensions that are measured.) Because of the large volume of 3-D points collected, the green cloud of points appears almost solid.

As the FDV scans the scene, the CGP instantaneously displays the generated 3-D points in another on-screen window. In about an hour, the CGP converts the thousands, or even millions, of data points into representative geometric surfaces, such as the best-fitting planes and cylinders. The software adds "false" color to the representation based on the intensity of light returned by the laser, allowing details as small as 2 to 6 mm to be seen. The CGP can convert the cloud of points into a 3-D surface model that can then be exported, if necessary, to a CAD application to create two-dimensional (2-D) drawings or 3-D models (see Fig. 4).

Unlike traditional surveying and scanning equipment, Cyrax does all the data acquisition and modeling in the field in an integrated (one-step) manner. These features offer clear advantages. Data can be easily spot-checked on-site to eliminate obvious mistakes. As the model is assembled, areas requiring more detail become apparent and more data can be easily acquired. If other views of an object need to be scanned to create its 3-D representation, the operator easily moves Cyrax to another location and repeats the data acquisition and imaging process. The CGP includes functionality that allows any number of scanning locations to be integrated into a single coordinate system; that is, the different data collections can be "zippered" together to create a single representation of the scanned object.

Applications

Cyrax's primary application is in the architecture, engineering, and construction industry, where it is being used to create as-built CAD drawings of large structures such as buildings, ships, refineries, manufacturing operations, and transportation infrastructure. CAD drawings of these structures are extremely important for new construction and for renovation and expansion work.

In addition, Cyrax can benefit numerous other markets. For example Cyrax has already demonstrated its ability to produce accurate geologic contour maps for industries such as mining. Listed here are just a few other possible applications that show the breadth of this technology.

- *Fine Arts.* Cyrax can document artifacts for preservation and restoration projects.
- *Cinema.* Computer models generated by Cyrax can be used to create realistic special effects. For example, caves measured by Cyrax were used to create background models in the film *Starship Troopers*.
- *Law Enforcement.* Cyrax can generate detailed, accurate archival images of accident and crime scenes.
- *Parts Listing.* Cyrax can recognize shapes in the scanned data and create parts lists for structures as complicated as oil refineries.
- *Facility Management.* Cyrax can provide accurate, detailed structural data throughout a facility's lifetime, allowing facility managers to easily assess the need for and feasibility of redesign as safety standards and facility needs change.

Cyrax has been tested by the U.S. Navy, Fluor Daniel, Raytheon, and Chevron. The results of this testing have produced accurate, detailed images that far exceed other available techniques. Although still a fledgling technology, Cyrax is already changing the way industry looks at 3-D imaging. We anticipate that Cyrax will have profound impacts in many applications, and it will affect our lives over the next few years in ways we can only begin to imagine.

Remote Ultralow-Light Imaging

R. C. Smith, S. K. Wilson, and K. Albright (P-21); R. Scarlett (NIS-6); C. Ho and A. Bird (NIS-2); R. Whitaker (NIS-4); and M. Hindman (NIS-3)

Much of scientific research depends on the ability to observe objects and phenomena that are invisible to the naked eye because of their small size, high speed, distance, or shielding. Many technologies exist to aid our observations of such objects, and these technologies are constantly advancing to capture more challenging phenomena with greater accuracy and precision.

One area in which the technology has advanced significantly in the last few decades is low-light imaging. Intensified imaging techniques have been in use for many years in applications such as night vision. These techniques allow us to see in the dark, but they provide only two-dimensional views and they do not address the problem of shielded objects. To address these shortfalls, we have developed a remote ultra-low light imaging (RULLI) sensor technology that simultaneously measures the position and absolute time of arrival of individual photons to provide data that are literally three-dimensional (3-D). Our RULLI technique allows us to create 3-D images of objects in low-light conditions—even objects that are moving or, in some cases, shielded from plain sight.

RULLI uses a microchannel plate/crossed delay line (MCP/CDL) detector and pulse absolute timing (PAT) electronics. The MCP/CDL detector is a hermetically sealed vacuum tube that contains a transparent window coated on the inside with visible-light-sensitive photocathode material, a Z-stack of three MCPs, and a CDL readout. Figure 1 shows how the MCP/CDL converts photons into electrical pulses. An active illumination system with known timing characteristics, such as a laser light pulse, is used to illuminate the object, and the returned photons are detected. An incident photon reflects from the object being imaged through the tube window of

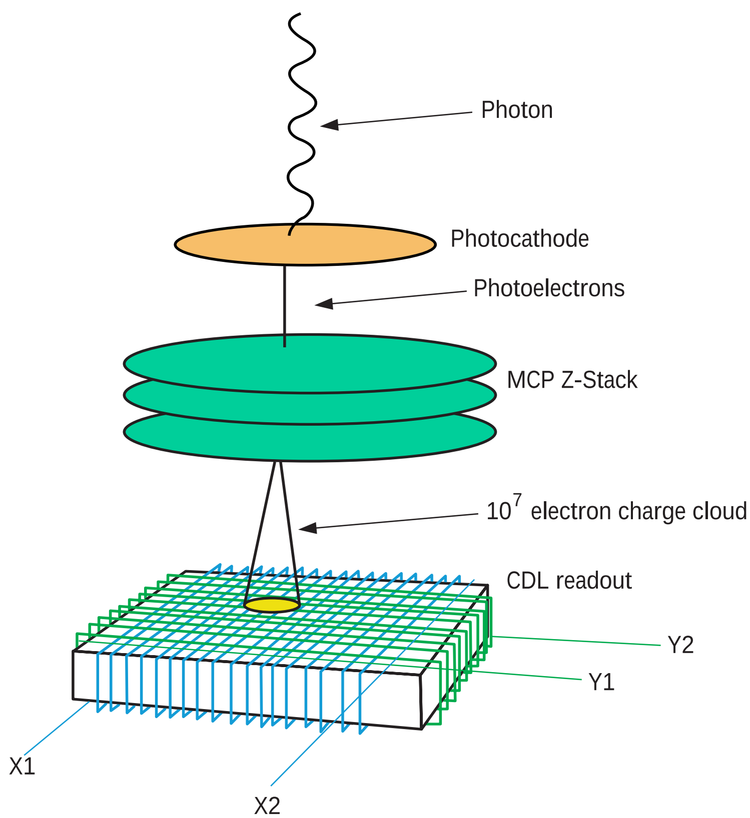


***Fig. 1** The MCP/CDL detector shown in this diagram converts photons into electrical pulses to record their precise arrival times. Using MDP/CDL technology combined with PAT electronics, our RULLI technique is able to acquire optical data at the single-photon level.*

the detector, where it strikes the photocathode material. With a finite probability—the quantum efficiency—the photon excites an electron, which leaves the photocathode surface. A bias voltage between the photocathode and the front of the detector's MCP stack attracts the photoelectron towards the first MCP, which consists of many tiny pores. A moderately high voltage, typically above 3,000 V (in vacuum), is applied between the front and the back of the MCP stack. Electrons propagating inside the pores rapidly multiply and avalanche, producing a charge cloud of around 10^7 electrons that is accelerated toward the layered CDLs.

The CDL readout consists of two wires in perpendicular helical windings, one outside of the other. These are supported by a common ceramic structure to fix their position. A ground plane is placed in the middle of the support structure. The charge cloud generated by a single photon event speeds toward and through the windings. Several delay lines interact with the charges, and the signal, after propagation through the windings, becomes a Gaussian-like electrical pulse presented at each of the two ends. With two layers of winding, each having two ends, we have four independent signals: X1, X2, Y1, and Y2.

Measuring the pulses' arrival times, we can reconstruct the position and arrival time of the initial photon event. This is accomplished using the PAT electronics, which is a fast and accurate timing technology that originated in the nuclear test program at Los Alamos. Each PAT board contains the analog and digital electronics to measure the pulse's arrival time relative to a stable clock. One key component of the PAT data acquisition system is a hybrid module known as the Time Interval Meter (TIM) circuit. The TIM measures the time interval between a start and stop signal with a resolution of 10 ps, an accuracy 20 ps for single pulse, and a deadtime of about 80 ns. The TIM uses a built-in constant fraction discriminator (CFD) triggering circuit to ensure that the signal is triggered at a fixed location of the pulse profile, relatively independent of the pulse amplitude. The digital output from the TIM is sent to fast digital electronics to collect, format, and record the data. Through custom algorithms, the position and absolute time of the incident photon event is calculated from the raw data.

To date, we have achieved the following performance in the laboratory: a full-width-half-maximum (FWHM) for a point source of 60 μm, and a timing accuracy for each photon of about 200 ps rms (root mean square) or 420 ps FWHM. We expect the current implementation to offer linear response up to a random count rate of about 10^6 counts per second before significant event degradation due to coincidence. In our literal 3-D imaging field and laboratory experiments (described below), the system had slightly degraded spatial and timing performance from the numbers above. As we continue to improve the system, we expect a point-source FWHM better than 30 μm, an absolute timing FWHM of about 100 ps, and a maximum count rate of 5×10^6 counts/second.

Fig. 2 These images, generated using the data from our laboratory experiment, clearly show that our RULLI technique resolved the 5-cm-high letters. The top image shows the data as a collection of points in 3-D space, with the closest points colored in red. The lower image shows the points as a surface under directed lighting. Our technique allows us to rotate and view these data from any angle.

The combination of MCP/CDL and PAT allows us to acquire optical data at the highest sensitivity possible: the single-photon level. By using the photon counting method to form the RULLI image we have no added readout noise. This means that the imaging limits of the system are dictated by the physics of the scene illumination, not by the detector readout. This level of sensitivity coupled with the timing precision allows the formation of high resolution images on moonless nights, even from moving platforms. Since we measure the CDL pulses at such high precision, we also have a very high resolution optical ranging system that requires the lowest of illumination power. In fact, the system is designed such that the illuminator returns to the detector, on average, one photon per incident pulse.

An end-to-end system with the capabilities needed for this literal 3-D imaging technique has been in operation since mid-1997. Using a commercial pulsed laser in combination with the RULLI technology, several experiments have been conducted under a variety of conditions.

To test RULLI's performance in a laboratory setting, we used a $30 \times 50 \times 5$-cm styrofoam block with 5-cm-thick styrofoam letters glued to the surface to spell out "LANL." The experiment was conducted in a dark laboratory at a distance of 7 m, and a pulsed laser triggered at 1.56 MHz was used for active illumination of the target. The laser was coupled to a 120-μm diameter, 7-m-long multimode optical fiber to achieve a more uniform illumination. The dark count over the entire detector area was about 600 counts per second, and the ambient light through the narrow band filter, including reflected light from two computer screens, contributed another 600 counts per second. The laser return accounted for about 1,200 counts per second. A number of data sets were collected with 240-second (4-minute) exposure times.

Using sophisticated information extraction algorithms, the extracted data were analyzed to separate the returned laser photons from the background photons. Background photons have a random arrival time, whereas the laser return photons have a known time signature that correlates with the laser pulse period. In this experiment, the culled data set contained about 288,000 photons compared to about 2,900 photons contributed from random background, giving a signal to background ratio of about 100:1. The culled data were then processed using a simple topography determination algorithm, and the images shown in Fig. 2 were generated. These images clearly show that we resolved the 5-cm height separation between the LANL letters and the solid styrofoam block.

In another experiment, we applied the RULLI technique to cloud studies. Because clouds are remote, change rapidly, and have structures from small to large scales, the existing tools to study real clouds experimentally have been very limited. We simulated a cloud with different scattering properties by mixing various amounts of fabric softener into a large fish tank filled with water. The $2\text{-} \times 3\text{-} \times 4$-ft tank was observed with the MCP/CDL/PAT sensor from a distance of 20 ft. A laser beam with sharp pulses at a regular rate of 1.6 MHz was focused close to the center of the field of view. Data were collected using several 60-second exposures.

Preliminary results of this experiment show the behaviors we expect from an optically thick cloud: Following an initial bright point-like spike from the prompt back-scattered photons at the air-tank interface, the photons spread out in spatial dimension and became dimmer. These late photons have undergone multiple scattering in the cloud and return towards the observer after long random walks, which displaces their exit position and angle. Detailed 3-D studies of these behaviors will significantly advance our understanding of clouds and other scattering media.

These experiments demonstrate that the RULLI technique offers a novel tool for imaging complex phenomena that could not be captured using previous techniques. The versatility of this measuring technique—the ability to detect individual photons and accurately measure their positions and arrival times—opens many avenues for gathering data on objects and phenomena that were previously unattainable. RULLI technology will be a solution for many research areas, including the study of small objects in low Earth-orbit, canopy density studies, astronomical imaging, optical brain imaging, and DNA studies. Our work will continue to improve this imaging technique and seek out novel applications. We anticipate that RULLI will reveal exciting phenomena in many areas where observation was previously impossible.

High-Energy-Density Physics at the Pegasus II Pulsed-Power Facility

David Oró (P-22) for the Atlas collaboration: Los Alamos National Laboratory (P Division, X Division, DX Division, MST Division), Lawrence Livermore National Laboratory, the All-Russian Scientific Institute of Experimental Physics (VNIIEF), and Bechtel Nevada

Introduction

The Pegasus II pulsed-power facility is used to conduct a variety of high-energy-density experiments that have applications to the nuclear weapons programs as well as to basic science. Forty-seven experiments were conducted at the facility during calendar years 1997 and 1998. Its unique capability of delivering strong, converging, shock-driven or adiabatically driven compressions in a macroscopic volume, combined with a well-developed suite of permanent and shot-specific diagnostics, have allowed physicists to conduct experiments that are providing important data to the weapons physics community. These data are currently being used to guide the development of particular models of material behavior in high-energy-density regimes and also to validate computer codes used to predict material behavior in these regimes.

The experiments performed at Pegasus II fall under three broad categories: hydrodynamic instabilities, material properties, and basic science and technology. Below, we present an overview of the facility and a discussion of each category with representative examples, and we conclude with a brief overview of the physics agenda for Atlas, the follow-on facility to Pegasus II that is now under construction.

Facility Overview

The Pegasus II facility consists of 144 capacitors arranged in a two-stage Marx bank with a maximum energy-storage capacity of 4.3 MJ. The Marx bank has a maximum erected voltage of 100 kV generating peak electrical currents as high as 12 MA in cylindrical inductive loads.

A typical load, also known as a liner, is shown in Fig. 1. It is made from 1100-series aluminum and is designed such that the inner surface remains solid during the course of the experiment while the liner is heated resistively by the electrical current. Experiments are conducted with or without targets in the interior depending on the nature of the experiment. The dimensions shown in Fig. 1 are for a standardized liner. Pegasus II can deliver ~0.5 MJ of kinetic energy to the 4.8-cm-diameter, 3.2-gram liner. The impact of this liner on an internal target with a diameter of a few centimeters results in shock pressures of 100–500 kbar in the target at liner velocities of ~3 km/s when driven under typical Pegasus II operating conditions. The liner's dimensions and composition are modified to meet the needs of the particular experiment. For example, we can apply a layer of dense material to the liner's inner surface to increase the ram pressure upon impact with a target. For a majority of experiments the liners and targets are constructed at the Los Alamos Target Fabrication Facility operated by the Materials Technology/Coatings and Polymers Group (MST-7).

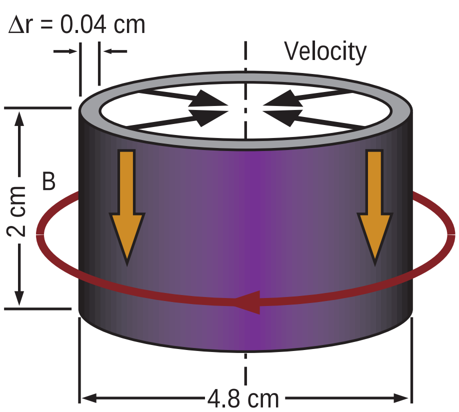


***Fig. 1** Diagram of a standardized aluminum liner for Pegasus II. As the Marx bank discharges, electrical current flows in the outer skin of the liner creating a strong magnetic field (B). The interaction of the current and magnetic field produces forces that implode the liner. In some experiments, a target is located inside the liner.*

A panoply of well-developed diagnostics is available for Pegasus experiments. Core diagnostics, those used on every shot, include current probes that measure the current pulse delivered to the liner and flash x-ray radiography with side views of the liner-target assembly. Different shot-specific diagnostics are deployed depending on the nature of the experiment and can include time-resolved pyrometry, particle holography, multiple-frame flash radiography along the liner-target cylindrical axis, laser backlighting, visible imaging of the target, optical pins, and VISAR (an acronym for "velocity interferometer system for any reflector").

Hydrodynamic Instabilities

An important area of research at the Laboratory is the study of the hydrodynamic flow of materials under extreme conditions. Of particular interest are the dynamics of instabilities that can be induced in hydrodynamic flow. Results of experiments are used to guide the development of models that describe the instabilities and to validate various hydrodynamic codes used at the laboratory. A number of experimental series studying hydrodynamic instabilities were carried out using Pegasus II during the last two years. One of these series, RTMIX, involves the study of the Rayleigh-Taylor (RT) instability, a phenomenon observed when acceleration occurs at an interface between two materials of different densities. The goal of these experiments is to diagnose and understand the growth of a mixing layer at an RT unstable interface and to understand the effects of material strength on the development of the mixing layer. Figure 2 shows a cross-section of the load for the first shot in this series, RTMIX 1. The liner consists of a composite cylinder with an outer 800-µm-thick aluminum cylinder in contact with an inner 200-µm-thick copper cylinder having an inner radius of 8 mm. The copper cylinder surrounds uniform, open-cell, polystyrene foam. The glide planes are made from a dense tungsten alloy to inhibit axial motion of the foam during the experiment.

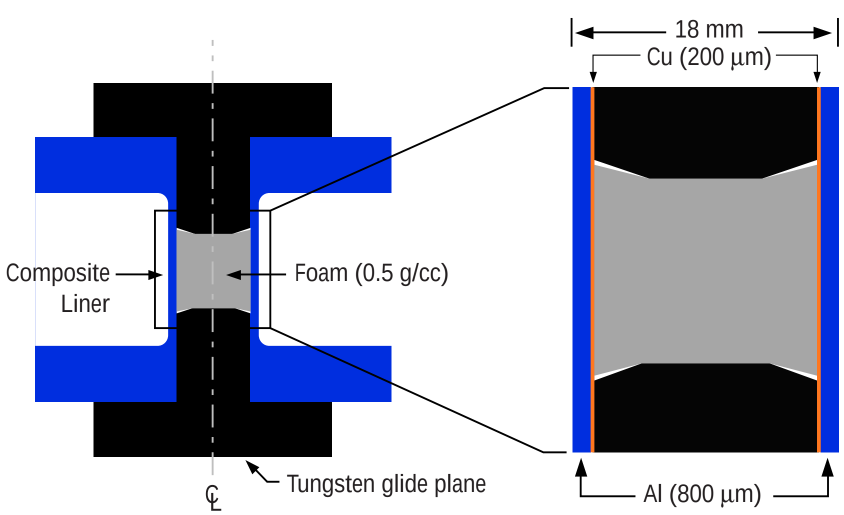


***Fig. 2** Side-view cross-section along the mid-plane of the load for RTMIX 1. During the experiment, the portion of the liner between the tungsten glide planes separates from the rest, imploding against the foam core. The function of the glide planes is to maintain electrical contact and therefore current flow through the liner as it implodes and, for the RTMIX experiment, to inhibit axial motion of the foam as it is compressed.*

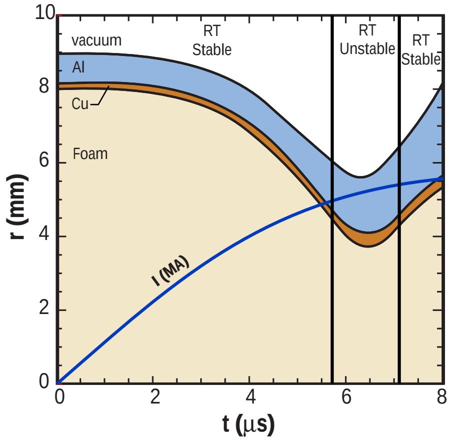


Fig. 3 1-D RAVEN simulation of an RTMIX experiment. The figure shows, as a function of time, the radius of the load interfaces and the current through the load. Also shown are the RT stable and unstable phases of the copper/foam interface.

Figure 3 shows a simulation of the experiment. The simulation is performed with RAVEN, a one-dimensional (1-D) magnetohydrodynamics (MHD) code. During the initial phase, the liner accelerates inward compressing the foam. As the compression continues, the liner decelerates, stops, and accelerates outwards—in effect, the liner bounces off the foam core. During the period of inward deceleration and outward acceleration the copper/foam interface is RT unstable. Of particular interest is the formation of a mixing layer at the copper/foam boundary as a result of the instability. The liner is designed such that the copper layer remains solid during the experiment and, therefore, it is expected that the copper's strength will play a role in the formation of a mixing layer at the interface through suppression of the instability. Analysis of the original radiographs from the RTMIX 1 experiment shows that the liner does undergo a bounce and an RT unstable phase. However, the data show no discernable evidence of a mixing layer at the copper/foam interface, which is consistent with analyses as well as two-dimensional (2-D) MHD simulations that include strength.

The configuration of the RTMIX 2 experiment was identical to RTMIX 1 with the exception that the inner surface of the copper cylinder had machined sinusoidal perturbations along the length of the cylinder. The perturbations had a wavelength of 1 mm and an amplitude of 50 µm on the upper half and 12.5 µm on the lower half of the cylinder. Analytical results and detailed 2-D MHD simulations predict that the small amplitude perturbation will not grow during the RT unstable phase of the experiment and the large amplitude perturbations will grow. However, the data show no evidence of growth of either amplitude perturbation during the experiment. The results from this experiment will be directly compared with the results from the RTMIX 4 experiment, which was conducted at the end of 1998. (Note that the numbers of the Pegasus experiments follow the order in which the loads for the experimental series are constructed, and not the shot order. The RTMIX 3 load exists, but it has not yet been fielded.) For RTMIX 4, the copper layer was replaced with a low-melting-point indium-tin eutectic alloy with the same perturbations as in RTMIX 2. It was expected that the alloy would melt during the experiment, allowing direct comparison of perturbation growth at an RT unstable interface with and without the effects of material strength. Data from RTMIX 4 are currently under analysis. Details of the RTMIX 1 and 2 experiments can be found in Sheppard, *et al.* [1], and Atchison and Sheppard[2].

Another experimental series performed during the past two years under the general category of hydrodynamic instabilities was a study of the vorticity and mixing generated in a target as a result of a shock-driven Richtmeyer-Meshkov (RM) instability, another hydrodynamic phenomenon associated with an interface between materials of different densities. For these experiments a standard liner was imploded onto a target generating a ~300 kbar shock in the target. Discontinuous target features seeded RM instabilities that resulted in the formation of jets and vortices. The results of these experiments are currently being employed by the computational design community to benchmark both legacy and Accelerated Strategic Computing Initiative (ASCI) hydrodynamic codes. Details of the comparisons to codes can be found in Guzik, *et al.*[3].

Material Properties

The properties of materials under extreme conditions is an area of active research at the Laboratory. A partial list of topics of interest in this category includes material failure through spall and ejecta, plastic deformations, strain and strain-rate effects, and interfacial friction. A number of experiments were carried out on Pegasus II during 1997–1998 to address various aspects of these topics. One recent series of experiments carried out in collaboration with physicists at Lawrence Livermore National Laboratory concentrated on the spallation of shocked aluminum targets. The goal of these experiments, known as the LLNL series, is to gain understanding of the failure mechanism and its role in the growth of subsequent instabilities and to investigate the role that material strength plays in these phenomena. In these experiments, a standard liner was imploded and collided with a target containing an aluminum cylinder. The collision of the liner with the target drives a shock into the target traveling toward the cylindrical axis. The resulting failure of the aluminum was recorded with multiple-frame flash radiography. Figure 4 shows a cross-section of the general target design for these experiments. The target is an aluminum cylinder with an inner radius of 1.0 cm and an outer radius of 1.3 cm surrounded by 0.2 cm of PMMA (Lucite). The

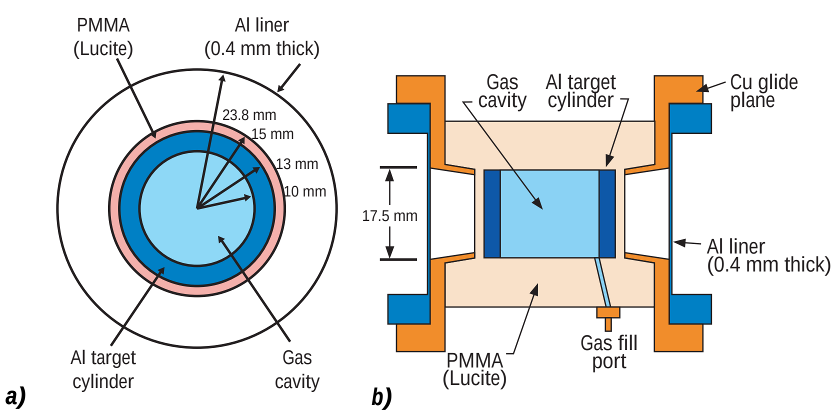
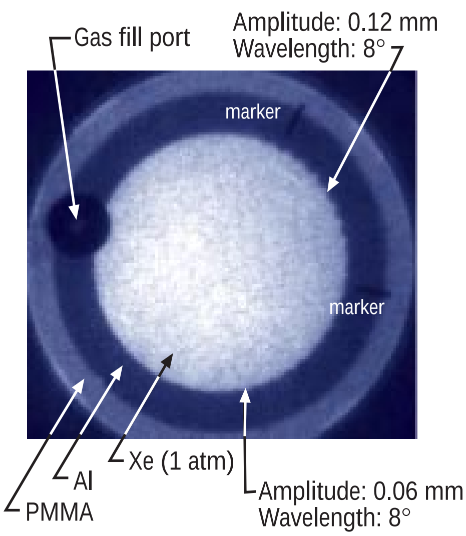
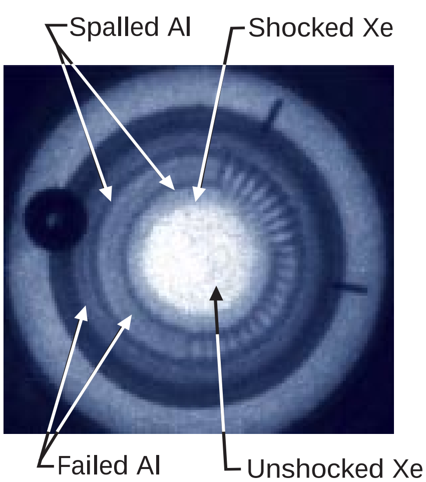


***Fig. 4** Top- (a) and side-view (b) cross-sections along the mid-planes of the liner/target design used for the LLNL series of experiments. During the experiment, current flows through the liner causing the portion between the glide planes to implode and strike the target. For several of the experiments, sinusoidal perturbations, as a function of azimuth, were machined on portions of the interior aluminum surface of the target.*



a)



b)

Fig. 5 Axial radiographs of the LLNL-5 experiment (a) before and (b) 3.38 μs after the liner has impacted the target. The impact velocity was 2.2 km/s resulting in a 140-kbar shock in the target. In (b), the shock has exited the aluminum target and is traveling toward the center in the xenon. Visible are the boundary between shocked and unshocked xenon, layers of spalled aluminum, regions of "failed" aluminum, and jets seeded by the perturbations.

central cavity is filled with 1 atmosphere of either xenon or argon. Only a portion of the inner surface of the aluminum cylinder is smooth. Parts of the interior surface have been machined with sinusoidal perturbations, the direction, amplitude, and wavelength of which have been varied with each experiment. The purpose of the perturbations is to act as a seed for instability growth.

Figures 5 and 6 show axial radiographs of the LLNL 5 and LLNL 6 experiments both before and during the implosion. Both targets are constructed from high-yield-strength 6061-T6-series aluminum. For LLNL 5, the liner was driven such that the shock pressure in the target was ~150 kbar, while for LLNL 6 the liner was driven such that the shock pressure in the target was ~500 kbar. Also, there are differences in some of the machined perturbations between both targets, as can be seen from the figures. The data show both layers of spalled aluminum and regions of "failed" aluminum, the exact nature of which is still to be determined. Also shown is the growth of jets that are seeded from the perturbations. The jets form from the "valleys" of the perturbations consistent with results from modeling. Detailed comparisons of these data with data from experiments using low-yield-strength, 1100-series aluminum targets and simulations using the Livermore CALE code, an adaptive Lagrangean-Eulerian hydrodynamic code with a full implementation of the Steinberg-Guinan strength model, are currently underway. More information about these experiments with results from the initial experiments can be found in Chandler, *et al.* [4]

Another experimental series falling under the material properties category is focused on material strength at large strains and strain rates. With Pegasus II, strains greater than 1 and strain rates of up to ~10^6 s^{-1} can be readily achieved in a material sample placed inside of an aluminum liner. In these experiments, a liner constructed of an outer layer of 1100-series aluminum and an inner layer of 6061-T6-series aluminum is imploded. The heating of the 6061-T6 layer from work done against the yield strength is measured with multichannel pyrometry. The temperature data as a function of time are unfolded to give the yield strength as a function of strain and strain rate. These experiments are providing data at conditions where none presently exists, and are being used to test the validity of strength models, some of which are employed in various hydrodynamic codes. Results from the initial experiments can be found in Bartsch, *et al.*[5]

Also under investigation using Pegasus II are frictional effects at shock-loaded material interfaces. For the Dynamic Friction 1 experiment, a liner was impacted on a target constructed with pie-piece-shaped wedges of aluminum and tantalum. The shock travels perpendicular to the aluminum-tantalum interfaces and, as a result of the different material characteristics of aluminum and tantalum, the shock travels faster in the aluminum resulting in a strong sheer between the aluminum and tantalum. The distortion of the materials at the interface is dependent on the frictional force between the materials. The distortion in the aluminum pieces is recorded with flash radiography and the data are being compared to simulations using empirical models of interfacial friction. Also, the tantalum pieces were recovered intact and the interfaces will be subjected to microstructural analysis. Details of the Dynamic Friction 1 experiment can be found in Hammerberg, *et al.*[6]

A series of experiments that continued into the 1997–1998 time frame involves the study of ejecta emitted from a shocked free surface. In these experiments a standard liner is imploded, striking a 400-µm-thick target cylinder. A shock propagates through the target cylinder reaching the inner surface, which causes ejecta to be emitted from the surface. The ejecta are imaged using holography, allowing number *vs.* size distribution to be determined. This work is focusing on understanding how target composition, surface finish, and shock strength affect the production of ejecta. A discussion of this series can be found in Sorenson, *et al.*[7]

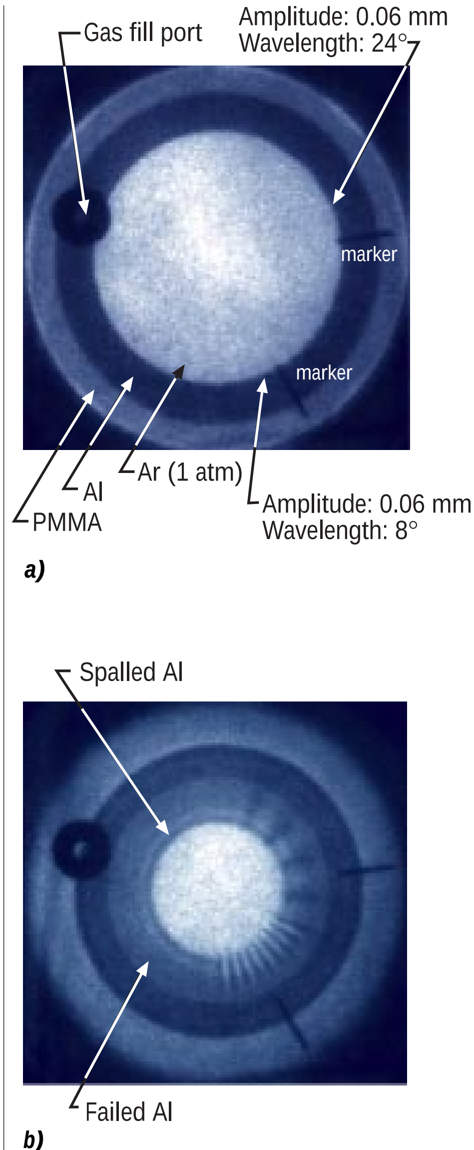


***Fig. 6** Axial radiographs of the LLNL-6 experiment (a) before and (b) 2.14 µs after the liner has impacted the target. The impact velocity was 4.5 km/s resulting in a 500-kbar shock in the target. In (b), the shock has exited the aluminum target and is traveling toward the center in the argon. Visible are a layer of spalled aluminum, a region of "failed" aluminum, and jets and density variations seeded by the perturbations. The shock in the argon is not visible in the radiograph due to the reduced x-ray absorption of argon.*

Basic Science and Technology

Megagauss 1 was the first in a potential series of experiments intended to use Pegasus II to generate intense magnetic fields in a macroscopic volume lasting for ~1 µs. The technique involves generating a millisecond timescale solenoidal field inside an unimploded liner with a pair of pulsed coils and then having the liner compress the field as it implodes on the microsecond timescale resulting in a magnetic field of multi-Megagauss intensity. It is expected that many electronics properties of materials should be greatly modified in the presence of such strong fields and, therefore, achieving such fields is of keen interest to the condensed matter community.

A number of experiments on Pegasus II over the last two years have been devoted to understanding the limitations of imploding a liner at near-melt conditions. Detailed 2-D MHD simulations show that under strong drive conditions the liner may break up as a result of the magnetic RT instability that occurs on the outer surface of the liner due to the magnetic field pressure pushing on the liner. Experimental data are needed to test the code predictions and have been provided by the Liner Stability (LS) series of experiments. In these experiments, the liners are radiographed during the implosion to determine the extent to which the instability has developed. For some experiments in the series, sinusoidal perturbations are machined on the outer surface of the liner to provide a known initial condition that will result in growth of the magnetic RT instability. The experimentally measured evolution of the instability can then be directly compared with code predictions using the same initial conditions. Results from the LS series can be found in Atchison, *et al.*[8]; Morgan, *et al.*[9]; and Reinovsky, *et al.*[10]

Los Alamos scientists have also collaborated with scientists from the All-Russian Scientific Institute of Experimental Physics (VNIIEF) in Sarov, Russia, in investigating the dynamics of liner implosion physics. Experiments with VNIIEF-designed liners are probing issues related to using materials other than 1100-series aluminum as the primary component in the liner. Details of the Russian experiments can be found in Buyko, *et al.*[11]

A series of experiments related to the Liner Stability and Russian experiments is addressing implosions at the maximum Pegasus II drive current of 12 MA. The motivation for the Megabar series is to develop a liner that can deliver multi-megabar shock pressures when it collides with a target. The liner consists of an 1100-series aluminum cylinder with a platinum layer on the inner surface. The aluminum carries the current and its low density allows the composite liner to achieve high velocity. The high-density platinum impactor layer results in a strong shock delivered to the target. The latest of these experiments, Megabar 3, achieved a liner velocity of ~7 km/s at impact on a 1-cm radius target with minimal bleed-through of the RT instability. This configuration has the capability of delivering a ~6 Mbar shock to a high-density target. Results of the Megabar 1 experiment can be found in Lee, *et al.*[12]

A number of experiments were carried out on Pegasus II to advance the technology of mechanical joints capable of carrying high current-densities. These experiments were performed in support of Atlas, the follow-on to Pegasus, which will achieve peak currents of 32 MA. Atlas requires the ability to make reliable joints between parts that can carry current densities of up to 51 kA/cm. For this work, several configurations were tested using different materials and geometries, and the results are being used to design the high-current-density connections in Atlas. Results from this work can be found in McCuistian, *et al.*[13]

Atlas: The Next-Generation Pulsed-Power Facility

For many applications in the nuclear weapons program and basic science, the energy of Pegasus II is insufficient to produce the conditions needed to benchmark computational predictions. These requirements have driven the development of the next-generation pulsed power driver, Atlas, now under construction. When complete in late 2000, Atlas will be a 23-MJ capacitor bank, capable of delivering over 30 MA of current to liner targets with a nominal 4-μs rise-time. The machine will consist of 12 pulsed-power modules, each driving a transmission line. All 12 transmission lines connect to a central powerflow channel, which provides a symmetric delivery of current to the target. The target will be contained inside a 2-m-diameter vacuum chamber. At the end of 1998, the final design of the machine was complete with many subsystems tested and many major components on order. When complete, the pulsed power system will be approximately 80 ft in diameter, and it will be supported by a suite of mechanical systems, controls, diagnostics, and data acquisition systems.

Atlas will deliver 2–5 MJ of kinetic energy to nominal 8-cm-diameter, 50-g liners, making possible many new experiments in dynamic materials properties and hydrodynamics. Many candidate experiments have now been identified and are being studied computationally. Among materials properties experiments of interest are absolute equation-of-state measurements along the hugoniot up to 20 Mbar and along the adiabat up to 5–10 Mbar. Both of these experiments will represent significant extensions of present capabilities. We are also designing hydrodynamic experiments with strongly coupled plasmas (plasmas in which the strength of the electrostatic potential of the ions is comparable to or greater than their thermal energy), for which very little prior experimental or theoretical understanding exists. A key feature of these experiments is that the high kinetic energy of Atlas will enable us to create an experimental region large enough that diagnostics can easily resolve hydrodynamic details. Other experiments under development include extension of the high-strain-rate, dynamic friction, and spallation experiments presently being conducted at Pegasus. Atlas should also provide interesting experimental environments for basic science. For example, generation of magnetic fields up to 2,000 T (20 MG) should be possible. In such fields, the cyclotron radius of a valence electron in a metal is reduced to less than the interatomic spacing, thus involving entirely new mechanisms of electron transport in condensed matter.

References

[1] M. G. Sheppard, *et al.*, "The Rayleigh-Taylor Mix Experiment on Pegasus," *11th IEEE International Pulsed Power Conference, Baltimore, Maryland, 1997,* G. Cooperstein and I. Vitkovitsky, Eds. (IEEE, Piscataway, 1997), p. 1399.

[2] W. L Atchison and M. G. Sheppard, "Studies of Acceleration Driven Instabilities in Convergent Geometries," Nuclear Explosives Code Developers Conference (Las Vegas, Nevada, October 1998), proceedings in press.

[3] J. A. Guzik, K. Koch, and the Antero Team, "Code Validation for the ASCI Antero Project," Nuclear Explosives Code Developers Conference (Las Vegas, Nevada, October 1998), proceedings in press.

[4] E. Chandler, P. Egan, K. Winer, J. Stokes, R. D. Fulton, N. S. P. King, D. V. Morgan, A. W. Obst, and D. W. Oro, "Use of the Pegasus Z-Pinch Machine to Study Inertial Instabilities in Aluminum: A Preliminary Report," 6th International Conference on the Physics of Compressible Turbulent Mixing (Marseilles, France, June 1997), proceedings in press.

[5] R. Bartsch, *et al.*, "Imploding Liner Material Strength Measurements at High-Strain and High Strain Rate," 8th International Conference on Megagauss Magnetic Field Generation and Related Topics (Tallahassee, Florida, October 1998), proceedings in press.

[6] J. E. Hammerberg, G. A. Kyrala, W. E. Anderson, R. D. Fulton, A. W. Obst, H. Oona, D. M. Oro, and M. D. Wilke, "A Pegasus Friction Experiment," Nuclear Explosives Code Developers Conference (Las Vegas, Nevada, October 1998), proceedings in press.

[7] D. S. Sorenson, B. Carpenter, N. S. P. King, D. Morgan, A. W. Obst, D. Platts, P. Rodriguez, J. Roberts, M. Stelts, J. Stokes, T. Taylor, and L. Veeser, "Ejecta Experiments at the Pegasus Pulsed Power Facility," *11th IEEE International Pulsed Power Conference, Baltimore, Maryland, 1997,* G. Cooperstein and I. Vitkovitsky, Eds. (IEEE, Piscataway, 1997), p. 1387.

[8] W. L. Atchison, R. J. Faehl, and R. E. Reinovsky, "Studies of Solid Liner Instability During Magnetic Implosion," Nuclear Explosives Code Developers Conference (Las Vegas, Nevada, October 1998), proceedings in press.

[9] D. V. Morgan, D. Platts, J. S. Shlachter, D. L. Martinex, and B. Carpenter, "Analysis of Radial Radiography for the Liner Stability Series at Pegasus: PGII-59, PGII-62, and PGII-63," *11th IEEE International Pulsed Power Conference, Baltimore, Maryland, 1997,* G. Cooperstein and I. Vitkovitsky, Eds. (IEEE, Piscataway, 1997), p. 1381.

[10] R. E. Reinovsky, *et al.*, "Stability of Magnetically Imploded Liners for High Energy Density Experiments," 8th International Conference on Megagauss Magnetic Field Generation and Related Topics (Tallahassee, Florida, October 1998), proceedings in press.

[11] A. M. Buyko, *et al.*, "Instability Growth in Magnetically Imploded, High Strength, Cylindrical Liners (Results of a Joint VNIIEF/LANL Experiment on the Pegasus-2 Facility)," 8th International Conference on Megagauss Magnetic Field Generation and Related Topics (Tallahassee, Florida, October 1998), proceedings in press.

[12] H. Lee, R. R. Bartsch, R. L. Bowers, W. Anderson, W. L. Atchison, R. E. Chrien, J. Cochrane, H. Oona, D. Platts, M. Rich, W. R. Shanahan, D. W. Scudder, J. Stokes, and L. Veeser, " Megabar Liner Experiments on Pegasus II," *11th IEEE International Pulsed Power Conference, Baltimore, Maryland, 1997*, G. Cooperstein and I. Vitkovitsky, Eds. (IEEE, Piscataway, 1997), p. 366.

[13] B. T. McCuistian, H. Davis, K. Nielsen, and B. Stone, "Atlas Current Tests Performed on Pegasus II," to be presented at the 12th IEEE International Pulsed-Power Conference (Monterey, California, 1999).

Subcritical Plutonium Experiments at the Nevada Test Site

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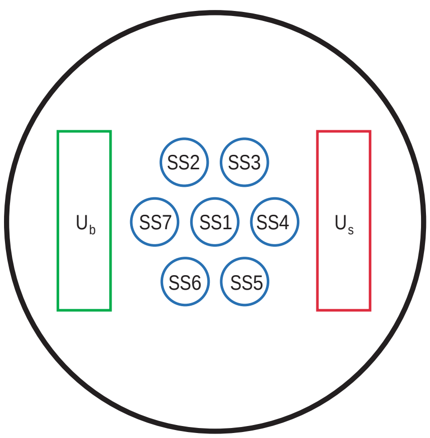

***Figure 1.** Schematic of the layout for the Rebound 170-GPa experiment. The U_b region contains the diagnostic for measuring flyer plate velocity (see Fig. 2). The U_s region contains the diagnostic for measuring the shock velocities in the plutonium samples (see Fig. 3). The circular regions labeled SS1 through SS7 are the locations of the sound speed samples.*

Introduction

In 1997 and 1998, a series of three subcritical plutonium experiments was conducted at the Nevada Test Site (NTS). These experiments, which are the first of their kind to be completed at NTS since the moratorium on underground nuclear testing in 1992, have several purposes. Foremost among these purposes is the study of plutonium physics and the maintenance of our readiness to resume underground nuclear testing should the need arise. These experiments were designed and fielded by the Dynamic Experiments (DX) Division in collaboration with the Physics Division and other Los Alamos divisions, as well as Sandia National Laboratory and Lawrence Livermore National Laboratory. The equation-of-state (EOS) measurement techniques were developed in DX Division, and they have been used by DX Division and its predecessors (GMX and M Divisions) for the past 40 years. Many of the diagnostic and recording techniques, especially for remote data collection, were developed by Physics Division for underground nuclear tests and pulsed power facilities.

The first two experiments, called Rebound and Stagecoach, were executed in July 1997 and March 1998, respectively. Their focus was the plutonium EOS. The third experiment, Cimarron, was conducted in December 1998. Its focus was the ejecta produced when a shock in the plutonium releases into the surrounding vacuum. The data from all three experiments are classified; therefore, this discussion will focus on the experiments themselves and the roles of the Detonation Science and Technology (DX-1), Hydrodynamic and X-Ray Physics (P-22), and Neutron Science and Technology (P-23) groups.

Rebound

The experimental techniques used on Rebound (and Stagecoach), such as the use of explosive-driven flyer plates to shock the samples and flash gaps to identify shock arrivals, were developed at Los Alamos National Laboratory in GMX Division and its successors over the last several decades. Adapting these techniques to the specific plutonium experiments described in this research highlight was done principally by the DX-Division authors listed above, but with significant contributions from the Physics Division. Physics Division personnel came to be involved because of the need to bring the signals out of the enclosed containment room (called the Zero Room because historically it was the room surrounding “ground zero” in underground nuclear testing) to record them at a remote location in the NTS environment. To accomplish this, the direct-view rotating-mirror cameras typically used at the GMX-, M-, and DX-Division firing sites to detect the flashgap signals (described in McQueen, *et al.*[1]) were largely replaced by fiber optics that took the light from the experiment to optical receivers or electronic streak cameras. For Rebound, DX-1, P-22, and P-23 collaborated on a series of seven local experiments to ensure that these diagnostic changes would retain high data quality and to refine the specific geometric parameters of the experiments. These local experiments were very successful.

The goal of Rebound was to study how small plutonium samples, typically a few tens of grams each, respond to shock compression at three specific high-pressure conditions—80 GPa (800 kbar), 170 GPa (1.7 Mbar), and 230 GPa (2.3 Mbar). Three separate experimental assemblies were fielded. Each of the assemblies used a 300-mm-diameter stainless-steel flyer plate that was driven down a barrel by high-explosives (HE) product gases until the plate struck a Lexan target plate holding several samples of gallium-stabilized, delta-phase plutonium. The thickness of the explosives charge, combined with the driver-plate thickness and run distance, determined the driver-plate velocity and consequently the pressures induced in the samples. The aim was to determine the shock Hugoniot (the locus of end points that can be reached in shock wave compression) and sound speed behind the shock front at all three pressures.

The success of the experiment was made possible by close collaboration among DX-1, P-22, P-23, and the other participants. DX-1 used its expertise in shock-wave physics to design experiments most likely to provide results in the EOS regime where the most serious uncertainties lay. Physics Division drew on its experience in underground testing to ensure high-quality data with precision adequate to meet the stringent requirements for such experiments. This is noteworthy because traditionally shock experiments are done under controlled laboratory conditions. In these fundamental subcritical experiments, the research is done underground in a “mining” environment, making it challenging to measure the fiducials, achieve accurate timing, and maintain experimental precision while doing the measurements remotely. Diagnostics included 112 fiber optic pins to measure the velocities and flatness of the flyer plates, shock velocities in the plutonium samples, and sound speeds in shocked plutonium; two electronic streak cameras, each with 35 data channels, which determined any tilt or bowing in the 170-GPa flyer plate and obtained high-time-resolution shock and flyer-speed data; and an energy release measurement to verify that the plutonium was never in a critical-mass configuration and that no self-sustaining fission reaction occurred. Following is a brief outline of the Rebound experiment, explaining what was done and why.

Figure 1 shows the schematic layout of the target plate for the 170-GPa assembly, which had the simplest configuration. The layout for the 800-kbar experiment was similar except two more samples, similar in size and shape to the sound-speed samples and placed near them, were used by DX-Division and Sandia researchers for VISAR (an acronym for “velocity interferometer system for any reflector”) measurements of the free surface velocity. The layout for the 2.3-Mbar experiment was also similar except a sample, similar in size and shape to the sound-speed samples and placed near them, was used by Livermore for a release-adiabat measurement. Figure 2 shows a detailed schematic for the diagnostic that measured flyer plate velocity (u_d). The diagnostic consists of fiber-optic pins behind steel of two thicknesses and a flash gap containing argon or xenon that emits light when shocked. Signals travel on fiber optics and are detected by photomultiplier tubes

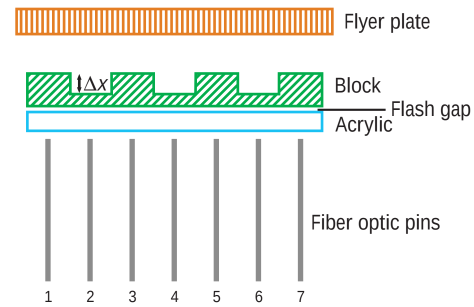

Figure 2. Schematic of the U_b block for measuring flyer plate velocity at the time of impact with the target plate.

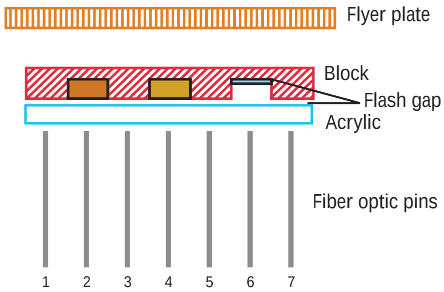

Figure 3. Schematic of the U_s block for measuring the sample shock velocities from the impact of the target plate.

(PMT), avalanche photodiodes (APD), and, when fast recording speed is particularly important, high-speed electronic streak cameras. Flyer plate velocity is determined from the arrival times of signals at two levels. When the flyer plate first strikes the block, a shock forms in the thick regions of the block; when the shock emerges, the flash gap light is detected by the odd-numbered pins. A short time later, the plate strikes the bottom of the notches, where it induces a shock of the same pressure, and that shock is detected by the even-numbered pins. The time difference between the even and odd pins (Δt) is related to notch thickness (Δx), flyer velocity (u_d), and the shock velocity in the block (u_s) by the following equation:

$$\Delta t = \Delta x(1/u_s - 1/u_d)$$

Flyer velocity can be determined by using the known EOS for stainless steel to eliminate u_s. The same principle is used with fiber optics coupled to the streak cameras, except that a closely-packed array of fibers replaces each pin. In this way we can measure detailed local variations in shock arrival times at the flash gap to determine spatial variations in the shock arrival profile, such as might arise from tilt or curvature of the flyer plate.

A detailed schematic for the diagnostic that measured the shock velocity in the plutonium samples is shown in Fig. 3. Two plutonium samples and a piece of transparent Lucite are placed in notches in a stainless steel block. The plutonium shock velocity is determined from the time delay between the start signal when the shock enters the samples, and the stop signals when it leaves the samples. The plutonium start signal is measured through the Lucite and also calculated from stop signals and the shock velocity in the block.

Optical signals proportional to the light intensity were taken from the experiments to the recording stations on fiber optic cables. Long fibers went to either PMT or APD receivers, some in an above-ground station ~1 km away, and some in an underground station about 150 m away. Longer fiber-optic lengths cause increasing distortion of the signals from dispersion, so the data requiring higher time resolution were recorded in the closer station. In the 1-km station, we used 40-nm-wide, 850-nm wavelength filters as a compromise to get adequate light into the receivers while limiting dispersion effects to a few nanoseconds. The fibers were carefully cross-timed in two different ways, one using an optical time domain reflectometer and the other using light from a diode laser injected into many fibers simultaneously. Fibers of similar lengths were timed relative to each other to within 1 ns. This fine control on the cross timing was necessary for the success of the experiment.

Redundant signals from the 170-GPa experiment were also taken a short distance, just a few meters, to a pair of streak cameras located just outside the Zero Room. One camera recorded the flyer speed and one the shock speeds. Before timing, these fibers were cut to lengths such that, as closely as we could determine before the experiment, the signals would all arrive simultaneously at the camera, allowing us to increase the camera sweep speed. We used five times as many fibers as pins (35 fibers each for U_b and U_s) to image the flashgap region so that we could better determine the shock profile across this region. The imaged spots were spaced along the line of pins so that the shock breakout was determined along the entire length of the flashgap. Although the technique was somewhat developmental, it gave a good measurement of the shock spatial profiles, as well as the shock and flyer speeds. This method also provided us a path for making these measurements on Stagecoach, where they were crucial to our obtaining good data on two of the experiments.

In addition to measuring fundamental quantities, such as shock and particle velocities, in plutonium samples, we also made measurements of a derivative quantity, the sound speed. Sound speed data provide valuable constraints to the EOS when combined with shock Hugoniot data. To measure sound speed, the rarefaction-overtake method described in McQueen, *et al.*[2], and shown in Fig. 4 was used. At the center of the target plate are seven samples of different thicknesses, each backed by a piece of high-density glass that serves as an analyzer material, emitting light when the shock arrives. The flyer plate strikes the samples, driving shocks into them and eventually into the glass. Meanwhile, another shock moves back through the flyer. When it reaches the interface with the driving HE gases, a rarefaction fan is reflected into the flyer, eventually moving into the samples and the glass. The pressure changes gradually in this rarefaction rather than suddenly as in a shock wave, but the rarefaction moves faster than the shock front and eventually overtakes it. The samples are thin enough so that, in most cases, the rarefaction overtake occurs in the glass, where it reduces the pressure and causes the light emitted by the glass to be reduced rapidly. The sound speed (the speed of the leading edge of the rarefaction wave), is determined from Δt, the time from first light in the glass until the light just begins to fade, for each sample thickness. Extrapolation to $\Delta t = 0$ gives the sample thickness for which the overtake would have occurred exactly at the sample-glass interface. The sound speed may be calculated from this thickness and other known quantities.

It is important to have an estimate of the signal levels before the shot so that the recording can be set up appropriately. For the flashgaps, the signals were only a few nanoseconds in duration, and their timing could be determined adequately even if they were slightly saturated. Compressed-gain amplifiers on some of the APDs also helped by increasing the dynamic range of the recording. For the sound speed data, however, any saturation would have caused us to lose the information on when the light began to dim. Compressing the signals would have also obscured the timing of the break. Furthermore, the sound-speed light levels from the lowest-pressure assembly were very low. We were able to obtain good sound-speed data by using redundant receivers and recorders with different gains, and for the low-pressure experiment we replaced the 850-nm APDs with ones based on GaAs photodiodes that operated around 1.3 µm. At these longer wavelengths the signals were large enough to make the experiment a success. Just as crucial were the light levels in the streak

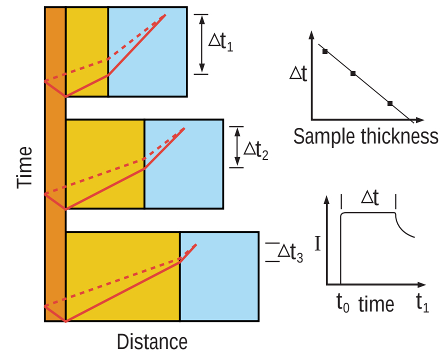

Figure 4. Rarefaction-overtake method for measuring sound speed in samples (yellow) backed by high-density glass (blue) and struck by a flyer plate (orange). The red lines in the sketch show time vs. position for the shock front (solid line) and the fastest rarefaction wave (dashed line). The lower graph illustrates a typical optical signal. The light comes on suddenly when the glass is shocked, remains constant for a time, Δt, until the pressure in the glass is reduced, and then drops gradually as the rarefaction fan overtakes the shock. The upper graph shows Δt for different sample thicknesses.

cameras. All of the levels were estimated from the signals in the seven local experiments.

After corrections for bow and tilt of the flyer plate and other experimental effects, the Rebound experiments produced three points on the shock Hugoniot for the plutonium alloy of interest. Preliminary uncertainties in the u_s-u_p plane were $< \pm 1.5\%$. Sound speeds for the same three pressures were determined with a similar uncertainty. Uncertainties in the release adiabat have not yet been published by Livermore, but they are expected to be slightly larger.

Stagecoach

Stagecoach, the second in this series of experiments, was conducted to improve our understanding of the plutonium EOS, to study the effects of plutonium aging on the EOS, and to develop new diagnostics for future subcritical experiments. The plutonium aging question is complex because plutonium's radioactivity can cause changes in material properties, and we must do experiments to see whether or not it does.

Stagecoach consisted of five experimental assemblies similar to those used in Rebound. Pressures in the plutonium samples ranged from 30 to 320 GPa. All five assemblies had a flyer velocity diagnostic like the one shown in Fig. 2 and a shock speed diagnostic like the one shown in Fig. 3. Each shock assembly included two samples, as shown in Fig. 3, and two of the assemblies included two such shock speed diagnostics. Each assembly had one sample of the plutonium alloy tested on Rebound and one or three aged plutonium samples, providing a test of the response of the aged plutonium at all five pressures. Overtake measurements were made for two assemblies. Four streak cameras were fielded to measure the shock and flyer speeds on the lowest-pressure assembly, where distortion of the flyer plate was of concern, and on the highest-pressure assembly, where the faster speeds made better timing essential. All of these measurements were conducted as described for Rebound, and they returned data of comparable quality at all five pressures.

In addition to the EOS work, we used this opportunity to test new diagnostics intended for measuring the surface temperature of samples on Cimarron. While the pressure, density, and internal energy can be determined from traditional shock-wave measurements of mechanical variables, temperature cannot, and therefore it requires a separate measurement. Shock temperature is an important parameter for benchmarking the EOS, and also for studying phenomena such as insulator-metal transitions, melting, and dissociation. Furthermore, the addition of temperature as a measured quantity, when combined with measured mechanical properties, allows determination of a complete EOS. Including this type of thermodynamic information is often a much more sensitive test of theoretical models such as the EOS than pressure-volume information alone. Temperature data are also useful for modeling phase changes, such as melting and the formation of ejecta at a free surface.

Pyrometry measurements of the shocked material provide the temperature only at the sample surface or interface, while it is the temperature behind the shock front that is of interest. However, the surface temperature is very useful in validating models that estimate the internal temperature. To obtain the free-surface temperature accurately it is necessary to eliminate ejecta from the field of view. One way to reduce the ejecta to manageable levels is by polishing the sample surface to a metallographic finish. However, plutonium is very difficult to polish and it oxidizes quickly, further compromising the surface finish. Another technique involves using a transparent window, or anvil, fastened to the plutonium surface to tamp the ejecta and maintain the release pressure at a higher value, closer to the shock pressure than for free-surface release. The interface temperature is thus closer to the internal temperature and the model validation should be more accurate. Lithium fluoride (LiF) is currently the best material for use as an anvil and as a window to transmit the radiation from the interface. Its heating under shock is low and its emissivity is small. It is important that there be no air or other shock-light-emitting material in the plutonium-LiF interface, although this is difficult to achieve because of the difficulty of polishing plutonium.

We fielded six-channel infrared pyrometers on both polished samples and samples with windows attached to determine which provides better results and to obtain data for release both into vacuum and LiF. We also fielded a comparison measurement of a polished surface and one with a coarser finish to determine whether the ejecta problem was severe enough to require polishing Cimarron samples. With the information from the Stagecoach pyrometers we were able to design the Cimarron temperature samples for optimum chances of success. Pyrometric measurements were also fielded by personnel from Sandia. Data quality and results were similar to ours.

Cimarron

As the nuclear weapons stockpile ages, it will be necessary to make occasional small changes in the materials used and the processes by which the manufacturing is done. Materials in nuclear weapons, including plutonium, HE, and plastics, are subject to change from effects such as oxidation and radioactivity. As it becomes necessary to remanufacture weapons or change out parts, we must be sure that the effects of any changes are minimized and that the changes are understood as much as possible. Furthermore, we need to make baseline measurements of current unaged weapons so that we will know when they have changed.

Cimarron was designed to study the ejecta emitted from a shocked plutonium surface. Ejecta production is sensitive to the surface roughness and oxidation, the material grain structure, and the shock profile. Cimarron diagnostics fielded by the Physics Division included holography to measure the distribution in ejecta size, x-ray shadowgraphy to measure ejected mass density, visible-light shadowgraphy to observe the ejecta cloud, fiber-optic pins to measure the shock timing and profile, pyrometry to measure the temperature of the shocked surface, and, as on the other subcritical experiments, a measurement of the energy release from the experiment to verify lack of criticality.

The in-line Fraunhofer holography technique, developed on the Pegasus pulsed-power system, has been adapted to make three-dimensional measurements of ejecta particles. Because the ejecta particles are moving at velocities of many millimeters per microsecond, a short-pulsed light source is required to stop their motion on film. Also, the explosive energy from the experiment is such that any hardware located nearby is destroyed. As a source, we used a 100-ps-pulsed, 200-mJ Nd:YAG laser with a 532-nm wavelength. This laser was developed by the Laboratory's Materials Science and Technology (MST) Division in collaboration with Bechtel Nevada. A 4.5-m-long optical relay system, consisting of 16 lenses, was designed to protect the laser and the holographic film, which were placed outside the Zero Room. The holography measurement is designed to resolve particles as small as 15 mm in diameter in a cylindrical image volume 1.5 cm in diameter and 6 mm in depth.

The x-ray imaging system also originated at Pegasus, the result of multi-year development of a unique wide-dynamic-range, four-frame framing camera; a newly-designed, blue-transmitting fiber-optic bundle; and modification of the stacked, pulsed x-ray sources used at Pegasus. The system has evolved so that ejecta can be measured over a 25-mm spatial extent at four arbitrary times. Time-dependent measurements were made possible by stacking four x-ray heads and independently triggering the anodes. Each source had a dose of 100 mRad at 30 cm. The heads were 50 to 70 cm from the imaged region and were nearly coaxial, so that they gave nearly the same view at four different times. The imaging system viewed a 4-mm-wide slot above the shocked surface using a powdered yttrium ortho-silicate (YSO) phosphor about 25 mm from the source and isolated from the plutonium region by a beryllium window. The phosphor was deposited directly onto a 120-mm-long fiber-optic plug, which was then directly coupled to a coherent fiber-optic bundle 2.7 m in length. The image passing through the bundle was reduced in size by a fiber-optic taper and connected to a blue-sensitive photocathode framing camera recently built by Bechtel Nevada. Finally, a cooled charge-coupled-device (CCD) camera coupled to the framing camera was used to record the images. The framing camera was fielded in the Zero Room in an environmentally-shielded enclosure. The increased sensitivity and uniformity of field resulting from substituting the coherent bundle for lenses permitted greatly-improved image quality. We also gained valuable experience to allow future, more complex Zero Room experiments with fewer penetrations of the containment wall.

The optical shadowgraphy system was designed around a pair of newly-developed Bechtel Nevada cameras capable of taking four images each. The four images can be gated individually with separate trigger times and intervals down to 50 ns. Light is taken from the Zero Room to the cameras using an optical line of sight, and the readout is done by a Pixel Vision 1,600 × 1,600-element CCD camera. System resolution for static images is about 25 μm over a 2-cm field of view. Although the system was initially intended to work with a ruby-laser backlighter, technical complications during setup dictated the removal of the laser. Consequently the shadowgraphy experiment's emphasis was modified to observe background light and background-light-illuminated ejecta, respectively, with somewhat slower gating of the cameras.

The pins and pyrometers were similar to those described for Rebound, except that the pins served to measure the shock arrival, not the plutonium EOS. Detailed results are not available because the experiment was executed only a few days before this article was written; however, it appears that all of the Physics Division diagnostics returned their data.

Conclusions

We have now completed three subcritical experiments at the NTS. The first two studied the basic EOS of plutonium and the third studied the ejecta produced under specific conditions. All three experiments returned high-quality data. In all three experiments, energy-release measurements showed that there were no neutrons or gamma-rays produced above the level of the background radiation from spontaneous fissions in the plutonium. Given the small plutonium samples involved in the experiments, this is not at all surprising. Other experiments not involving Physics Division personnel were not described in this research highlight, but it is worth noting that DX Division and Sandia researchers fielded optical interferometers to measure spall strength, surface velocity, and total ejecta mass, while researchers from Livermore measured shock releases on Rebound and Stagecoach. Excellent data were obtained on these experiments.

Presently there are no firm plans for further EOS measurements on NTS subcritical experiments. Although more data are needed, the funding situation will not now support another major EOS experiment. Should the need for data persist, we hope to revive the EOS work on JASPER, the plutonium gas gun to be built at NTS. We will continue the ejecta studies begun on Cimarron and also begin to study plutonium spall strength on subsequent subcritical experiments.

References

[1] R. G. McQueen, S. P. Marsh, J. W. Taylor, J. N. Fritz, and W. J. Carter, "The Equation of State of Solids from Shock Wave Studies," in *High-Velocity Impact Phenomena*, R. Kinslow, Ed. (Academic Press, New York, 1970), Chap. VII.

[2] R. G. McQueen, J. W. Hopson, and J. N. Fritz, "Optical Technique for Determining Rarefaction Wave Velocities at Very High Pressures," *Review of Scientific Instruments* 53, 245 (1982).

Fundamental Symmetries with Magnetically Trapped ^{82}Rb

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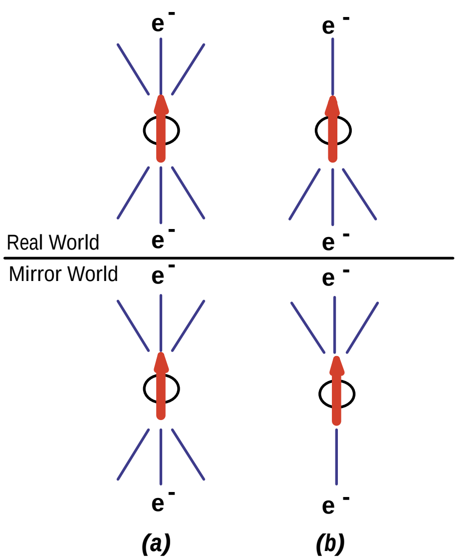

***Fig. 1** (a) If parity (or space-reflection symmetry) were preserved in nuclear beta decay, no asymmetry would be detected in the distribution of electrons relative to the spin-orientation of the parent nucleus. In this scenario, the real world and mirror world would be indistinguishable. (b) Due to parity violation, electrons observed in nature exhibit an asymmetry in their angular correlation with the nuclear spin direction.*

Theories of fundamental processes develop in tandem with our understanding of symmetry principles and the invariance of physical laws under specific transformations in space and time. Of the four fundamental forces in nature (strong, electromagnetic, weak, and gravity), the weak interaction is unique in that it violates parity, or space-reflection, symmetry. Four decades have passed since the first suggestion by Lee and Yang that parity could be violated in weak interactions,[1] and the subsequent discovery by Wu *et al.* of parity violation in the beta decay of polarized cobalt-60 (^{60}Co).[2] Today, maximal violation of parity is described in the standard model by a universal interaction between leptons and quarks. This model is based on empirical data established by nuclear and particle physics experiments during the second half of this century. Nonetheless, the origin of parity violation and how it is related to other conservation laws and physical processes is unresolved and marks one of the central mysteries of modern physics. Within the framework of modern gauge theories, an underlying theme speaks of spontaneously broken symmetries wherein discrete symmetries, such as parity, are restored at higher energy scales. Low-energy physics experiments that exploit nuclear beta decay continue to offer a means to probe the fundamental origin of parity violation and, more generally, the helicity structure of the weak interaction.[3]

Parity violation is manifest in nuclear beta decay as an asymmetry in the angular distribution of beta particles emitted relative to the spin orientation of the parent nucleus (see Fig. 1). In pure Gamov-Teller (GT) transitions, wherein the nucleus undergoes a change in angular momentum by one unit, the electrons are emitted preferentially in a direction opposite to the spin of the parent nucleus. Furthermore, since both the electron and the neutrino emerging from the decay must each carry away one-half unit of angular momentum (intrinsic spin) it follows that the electron must carry off its spin angular momentum aligned anti-parallel to its direction of motion. In other words, the weak interaction is *left-handed.* These, and other, observations have culminated in what we now call the standard model of weak interactions that couples leptons and quarks according to the famous vector-axial vector (V-A) prescription.

The pure GT transitions still offer the most direct route to study parity violation because they proceed solely through the axial-vector couplings responsible for parity violation. Historically, however, studies of pure GT transitions have been limited for lack of good candidates, namely reasonably long-lived and unhindered transitions. Hindered (as opposed to allowed) transitions exhibit energy-dependent behavior beyond the standard (allowed) beta spectrum, which can complicate the analysis of a precision experiment. Technical difficulties have also limited the degree of absolute nuclear polarization achievable to about 60–70%. Because uncertainty in polarization is directly reflected as an uncertainty in the correlation coefficient being measured, it is desirable to design experiments where polarization arbitrarily close to 100% can be obtained. In addition, experiments making use of solid sources are limited by the difficulties in understanding electron scattering and energy loss effects that can masquerade as a false asymmetry. For these reasons there is little hope of breaching the 1% precision level in the study of pure GT decays using conventional techniques, and one is forced to look to new technologies to improve the situation. It is now possible to envision a new generation of pure GT experiments by exploiting optical and magnetic traps for radioactive atoms.

Our research aims specifically at exploiting magnetically trapped rubidium-82 (^{82}Rb) in a new generation of fundamental symmetry experiments. ^{82}Rb, a pure and allowed GT beta decay nucleus, has the appropriate atomic structure and lifetime (75 seconds) to be exploited in a magneto-optical trap. A prototype experiment has been mounted to measure the positron-spin correlation coefficient (A) from polarized ^{82}Rb in a magnetic TOP (time-orbiting potential) trap. In a TOP trap, an essentially massless source of highly polarized ^{82}Rb atoms is suspended in vacuum in the form of a localized cloud ~1 mm in diameter, and the direction of the magnetic bias field aligning the nuclear spin rotates uniformly in a plane.[4] We propose to exploit this rotating beacon of spin-polarized ^{82}Rb nuclei to measure the parity-violating correlation as a continuous function of the positron energy and emission angle relative to the nuclear spin orientation. The positron spin correlation function can be defined,

$$\chi(E,\Theta) = AP\beta(E)\cos\Theta \ ,$$

where E is the electron energy, $\beta(E)$ its velocity relative to light, Θ the angle between the electron momentum vector and the nuclear spin orientation, and P the polarization of the parent nucleus. We are planning an experiment to measure, on an event-by-event basis, the energy of the positron registered in a plastic scintillator, which will allow the determination of $\beta(E)$. Together with a snapshot of the magnetic field configuration, this will allow us to reconstruct the angle of the nuclear polarization vector relative to the momentum vector of the emitted positron ($\cos\Theta$).

While several groups are pursuing fundamental weak-interaction experiments with trapped atoms, the challenge remains to harness sufficient numbers to undertake a meaningful experiment. ^{82}Rb is the daughter product following electron-capture of the parent, strontium-82 (^{82}Sr). The ^{82}Sr source is produced at the isotope production facility of the Los Alamos Neutron Scattering Center (LANSCE) by 750-MeV proton irradiation of a molybdenum target. The strontium sample is then handled at the Chemical Science and Technology (CST) Division’s hot cell, where the target is dissolved in hydrogen peroxide and the strontium fraction is extracted using an ion-exchange column. The ^{82}Rb is electrostaticly extracted from an ^{82}Sr ion source via a mass separator, where it is implanted into an yttrium foil. The ^{82}Rb is then released as a

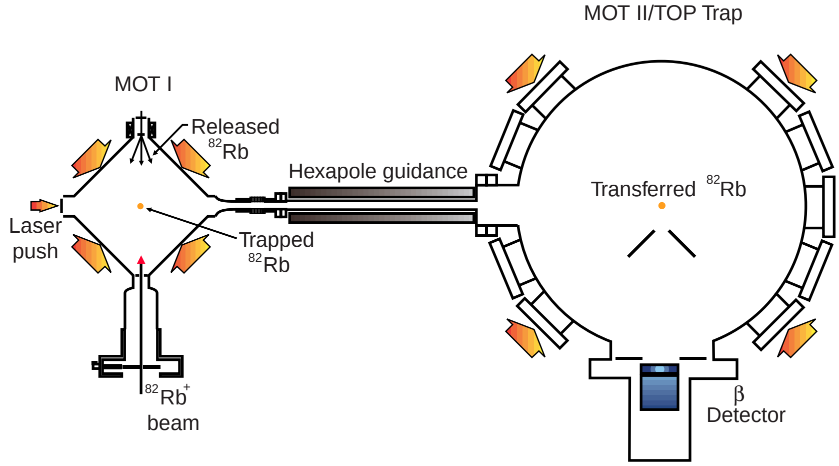

Fig. 2 Schematic diagram of the apparatus used to trap, transfer, and retrap ^{82}Rb atoms.

neutral atom by heating the foil, and it is subsequently released to a magneto-optical trap (MOT-I), as shown in Fig. 2. The neutral ^{82}Rb ions are trapped in MOT-I and confined to a 1-mm-diameter cloud at the center of a glass cell. Using an optical push-beam, the ^{82}Rb atoms are then transferred through a hexapole guide tube to a second magneto-optical trap (MOT-II). In MOT-II, they are trapped in a vacuum chamber housing the positron detector hardware. MOT-II is implemented with a set of magnetic bias coils, which are used to polarize the ^{82}Rb atoms in the TOP-trap configuration. The TOP-trap is rabily switched on such that the direction of the magnetic bias field aligning the nuclear spin rotates uniformly in a plane. The rotating, spin-polarized ^{82}Rb nuclei can then be used to measure the parity-violating correlation.

With an ^{82}Rb ion source, mass separator, and MOT in place, we have demonstrated a world record by trapping several million radioactive ^{82}Rb atoms.[5] Fig. 3 summarizes the data from these experiments. We have also demonstrated a transfer efficiency of 50% in loading the atoms into MOT-II, where the ultra-high vacuum environment provides a trapping lifetime of 500 seconds. The combination of the large trapping numbers and long trapping lifetime makes us well poised to accumulate sufficient statistics for a precision experiment.

Design of the TOP trap for fundamental symmetry investigations has posed a significant challenge. Large magnetic fields are required to achieve sufficient global polarization of the atom cloud while, at the same time, care must be taken to ensure that energy-dependent magnetic acceptance effects do not produce a false positron-spin asymmetry. Extensive Monte Carlo simulations have been implemented for the design and construction of the TOP trap to minimize systematic effects, and the hardware, including a first generation positron-telescope, are in place. We have only just begun to fully exercise our TOP trap and anticipate performing prototype measurements of the positron-spin correlation function during the coming months.

Prototype experiments will be geared to address a number of experimental details to assess our ultimate sensitivity in measuring

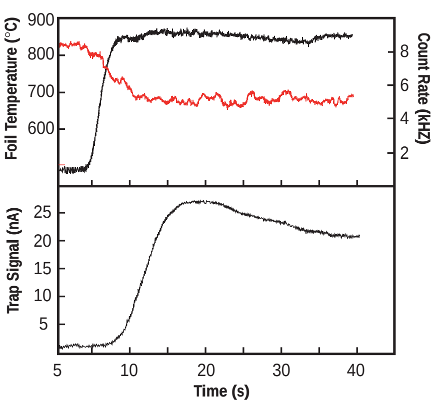

Fig. 3 Data recorded while trapping ^{82}Rb atoms in MOT-I. The top panel shows the release of atoms from the yttrium foil (red curve) upon heating the foil to a temperature of 850°C (black-curve). The lower panel shows the modulated fluorescence signal as measured with a photomultiplier and lock-in amplifier (blue-curve) as atoms are trapped at the center of MOT-I. The peak signal of 25 nA corresponds to a trapping signal of some six million radioactive atoms, and the characteristic half-life of ^{82}Rb is observed as the radioactive atoms decay.

the positron-spin correlation coefficient. Perhaps the most challenging detail facing us is in our ability to ascertain the absolute polarization of the atom cloud. With systematic issues under control, the ultimate sensitivity of the experiment could be limited at the 0.5% level of accuracy due to energy-dependent, recoil-order corrections that are complicated by nuclear structure in complex nuclei. It is possible, however, to recover the recoil-order correction in a novel manner by exploiting both the asymmetry and higher multipole anistropy terms. Both terms are available in our experiment since the correlation function can be mapped out as a continuous function of both positron energy and emission angle. In this way, the data could be exploited in the search for physics beyond the standard model while extracting the recoil-order corrections experimentally and without reliance on difficult and inaccurate calculations.

We have an opportunity at Los Alamos to play an active and lead role in the next generation of fundamental symmetry experiments that exploit trapped radioactive atoms. The combination of nuclear chemistry and atomic, nuclear, and particle physics capabilities inherent in this collaboration gives us a unique potential for precision and world-class experiments that are unlikely to take place anywhere else in the world in the foreseeable future. Indeed, the success of the proposed experiment would mark the first fundamental nuclear physics experiment that exploits a TOP-trap and the first effort to measure the positron-spin correlation as a continuous function of positron energy and emission angle.

References

[1] T. D. Lee and C. N. Yang, “Question of Parity Conservation in Weak Interactions,” *Physical Review* 104, 254 (1956).

[2] C. S. Wu, E. Ambler, R. W. Hayward, D. D. Hoppes, and R. P. Hudson, “Experimental Test of Parity Conservation in Beta Decay,” *Physical Review* 105, 1413 (1957).

[3] J. Deustch and P. Quin, “Symmetry-Tests in Semileptonic Weak Interactions,” and P. Herczeg, “Beta Decay and Muon Decay Beyond the Standard Model,” in *Precision Tests of the Standard Electroweak Model, Advanced Series on Directions in High Energy Physics*, Vol. 14, P. Langacker, Ed. (World Scientific, New Jersey, 1995).

[4] W. Petrich, M. H. Anderson, J. R. Ensher, and E. A. Cornell, “Stable, Tightly Confining Magnetic Trap for Evaporative Cooling of Neutral Atoms,” *Physics Review Letters* 74, 3352 (1995).

[5] R. Guckert, X. Zhao, S. G. Crane, A. Hime, W. A. Taylor, D. Tupa, D. J. Vieira, and H. Wolnik, “Magneto-Optical Trapping of Radioactive ^{82}Rb Atoms,” *Physics Review A* 58, R1637 (1998).

Advances in Quantum Computation

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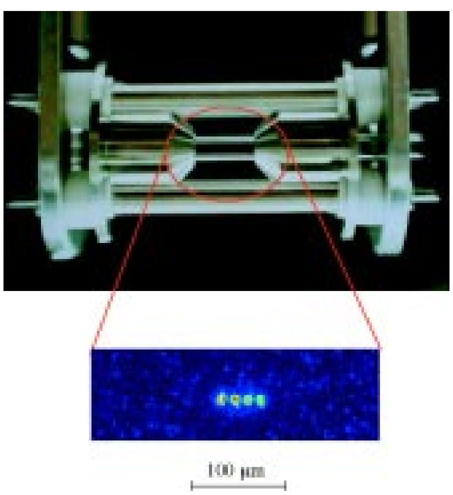

***Fig. 1** A string of four calcium ions localized by laser cooling in the ion trap. The trapping region is about 1-cm long by 1.8-mm high. The image is formed by the ion fluorescence in the 397-nm cooling laser beam.*

The representation of information by classical physical quantities such as the voltage levels in a microprocessor is familiar to everyone. But over the past decade, quantum information science has been developed to describe binary information in the form of two-state quantum systems, such as photon polarization states. (A single bit of information in this form has come to be known as a "qubit.")

With two or more qubits it becomes possible to consider quantum logical-"gate" operations in which a controlled interaction between qubits produces a (coherent) change in the state of one qubit that is contingent upon the state of another. These gate operations are the building blocks of a quantum computer. In principle, a quantum computer is a much more powerful device than any existing or future classical computer because the superposition principle allows an extraordinarily large number of computations to be performed simultaneously. In 1994 it was shown that this "quantum parallelism," which has no counterpart in conventional computation, could be used to efficiently find the prime factors of composite integers.[1] Integer factorization and related problems that are computationally intractable with conventional computers are the basis for the security of modern public-key cryptosystems. However, a quantum computer running at desktop personal computer speeds could break the keys of these cryptosystems in only seconds (as opposed to the months or years required with conventional computers).[2] This single result has turned quantum computation from a strictly academic exercise into a subject whose practical feasibility must be urgently determined.

The architecture of a quantum computer is conceptually very similar to a conventional computer: multiqubit, or "multibit," registers are used to input data; the contents of the registers undergo logical-gate operations to effect the desired computation under the control of an algorithm; and, finally, a result must be read out as the contents of a register. The principal obstacles to constructing a practical quantum computer are (1) the difficulty of engineering the quantum states required; (2) the phenomenon of "decoherence," which is the propensity for these quantum states to lose their coherence properties through interactions with the environment; and (3) the quantum measurements required to read out the result of a quantum computation. The first proposals for practical quantum-computation hardware, based on various exotic technologies, suffered from one or more of these problems. However, in 1994 it was proposed[3] that the basic logical-gate operations of quantum computation could be experimentally implemented with laser manipulations of cold, trapped ions: a qubit would comprise the ground (S) state (representing binary 0) and a suitably chosen metastable excited state (to represent binary 1) of an ion isolated from the environment by the electromagnetic fields of a linear radio-frequency quadrupole (RFQ) ion trap. Figure 1 shows schematically how the constituent parts of an ion trap quantum computer come together.

The principal components of this technology are already well developed for frequency-standard and high-precision spectroscopy work. Existing experimental data suggest that adequate coherence times are achievable, and a read-out method based on so-called “quantum jumps” has already been demonstrated with single trapped ions. We are developing an ion-trap quantum computer experiment using calcium ions, with the ultimate objective of performing multiple gate operations on a register of several qubits (and possibly small computations) to determine the potential and physical limitations of this technology.[4]

The heart of our experiment is a linear RFQ ion trap with cylindrical geometry in which strong radial confinement is provided by radio-frequency potentials applied to four “rod” electrodes, and axial confinement is produced by a harmonic electrostatic potential applied by two “end caps” (Fig. 1). After laser cooling on the 397-nm transition from the ground state (S) to the excited state (P), several calcium ions will become localized along the ion trap’s axis because their recoil energy (from photon emission) is less than the spacing of the ions’ quantum vibrational energy levels in the axial confining potential. Although localized to distances much smaller than the wavelength of the cooling radiation, the ions nevertheless undergo small amplitude oscillations, and the lowest frequency mode is the axial center of mass (CM) motion in which all the ions oscillate in phase along the trap axis. The frequency of this mode, whose quantum states will provide a computational “bus,” is set by the axial potential. The inter-ion spacing is determined by the equilibrium between this axial potential, which tends to push the ions together, and the ions’ mutual Coulomb repulsion. For example, with a 200-kHz axial CM frequency, the inter-ion spacing is on the order of 20 μm.

The first excited state of a calcium ion has a long radiative lifetime (~1 second), so the transition from this level (D) to the ground state has such a narrow width that it develops upper and lower sidebands separated from the central frequency by the CM frequency. With a laser that has a suitably narrow linewidth and is tuned to the lower sideband, an additional stage of laser cooling is used to prepare the “bus” qubit (CM vibrational mode) in its lowest quantum state (“sideband cooling”). On completion of this stage, the quantum computer is prepared with all qubits in the “zero” state, ready for quantum computation (see Fig. 2).

The narrow-linewidth laser tuned to the S-D transition is the essential tool for changing the contents of the quantum register of ions and performing quantum logical-gate operations. By directing this laser at an individual ion for a prescribed time, we will be able to coherently drive the ion’s quantum state between the two qubit levels that the ion represents. An arbitrary logical operation can be constructed from a small set of elementary quantum gates, such as the so-called “controlled-NOT” operation, in which the state of one qubit is flipped if a second qubit is in the “1” state but left unchanged if the second qubit is in the “0” state. This gate operation can be effected with five laser operations using quantum states of the ion’s CM motion as a computational bus to convey quantum information from one ion to the other. The result of the quantum computation can be read out by turning on the S-P laser. An ion in the “0” state will fluoresce, whereas an ion in the “1” state will remain dark. So, by observing which ions fluoresce and which are dark, a value can be obtained.

To date, we have succeeded in laser-cooling calcium ions into crystalline strings in our ion trap, which will be used as a quantum register. We used a charge-coupled device (CCD) camera to image ion strings of various lengths (see Fig. 1).

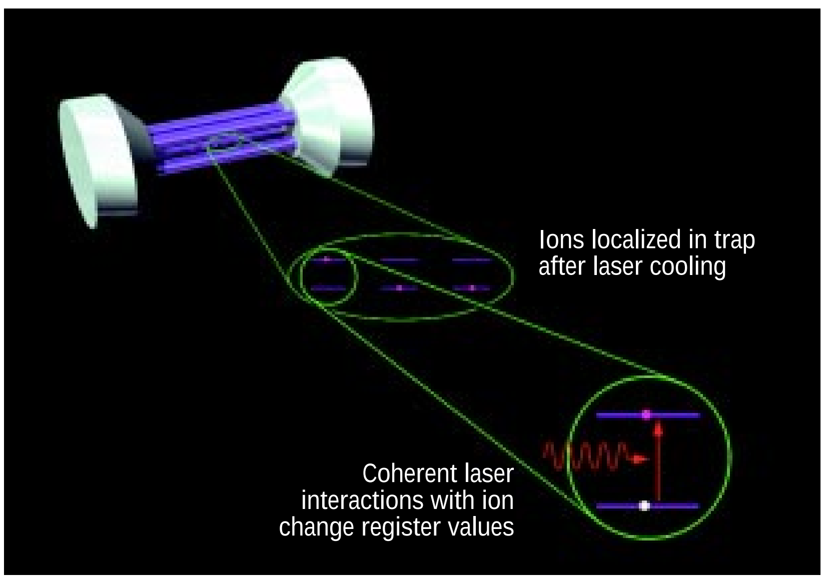

***Fig. 2** A schematic representation of an ion trap quantum computer. Within the cylindrical RFQ ion trap, ions are radially confined by radio-frequency potentials applied to the four rod electrodes and axially confined by a harmonic electrostatic potential applied to the end caps. After a first stage of laser cooling, ions become localized along trap's axis. A second stage of laser cooling cools the ions to their lowest quantum states. The quantum computer is then ready for computation.*

In addition, we have developed an optical system that can direct the computational laser beam with low-crosstalk to individual ions and rapidly switch the beam from ion to ion as required for quantum computational operations. We have also studied the intrinsic computational potential of ion-trap quantum computers. By taking into account the relevant decoherence mechanisms, we have found that on the order of one million gate operations could be performed on registers of 50 or so ions.[5] This is a tremendous amount of quantum computation relative to the current state of the art: one logic operation on two qubits. We have also performed a theoretical study of the mechanisms causing ion heating, which limit the amount of computation possible in an ion trap system, and we have determined how the heating rate depends on critical parameters such as the trap dimensions and frequencies. Because a quantum computer can create an arbitrary quantum state using quantum logic operations, this computational capacity opens up a wide variety of quantum-mechanics experiments in domains that are today inaccessible. We expect therefore that ion-trap quantum computers will allow us to explore quantum computation and the foundations of quantum mechanics.

References

[1] P. W. Shor, "Algorithms for Quantum Computation: Discrete Logarithms and Factoring," 35th Annual Symposium on the Foundations of Computer Science (Santa Fe, New Mexico, 1994), *Proceedings of the 35th Annual Symposium on the Foundations of Computer Science*, S. Goldwasser, Ed. (IEEE Computer Society Press, Los Alamitos, California, 1994) p. 124–134.

[2] R. J. Hughes, "Crytography, Quantum Computation, and Trapped Ions," *Philosophical Transactions of the Royal Society of London A* 356, 1853 (1998).

[3] J. I. Cirac and P. Zoller, "Quantum Computation with Cold, Trapped Ions," *Physics Review Letters* 74, 4094 (1995).

[4] R. J. Hughes, *et al.*, "The Los Alamos Trapped Ion Quantum Computer Experiment," *Fortschritte der Physik* 46, 329 (1998).

[5] R. J. Hughes, *et al.*, "Decoherence Bounds on Quantum Computation with Trapped Ions," *Physical Review Letters* 77, 3240 (1996).

Practical Free-Space Quantum Key Distribution

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Introduction

Quantum cryptography was introduced in the mid-1980s[1] as a new method for generating the shared, secret random number sequences, known as cryptographic keys, that are used in cryptosystems to provide communications security. Existing methods of key distribution derive their security from the perceived intractability of certain problems in number theory (which grow more vulnerable as computers grow more powerful), or from the physical security of the distribution process (which often depends upon couriers, increasing the likelihood that the key might be compromised). The appeal of quantum cryptography is that its security is based on the natural laws governing the behavior of photons, laws that solidly guard against the possibility of successful eavesdropping and interception.

In past years, our team has played a major role in demonstrating that quantum key distribution (QKD) is possible over multikilometer distances of optical fiber.[2, 3, 4] Free-space QKD, however, presents a greater challenge. The success of free-space QKD depends on the ability to transmit and detect single photons against a high background (that is, interference from other photon sources) and through a turbulent medium (the air). Building on previous efforts to demonstrate free-space QKD[5,6] we have developed and successfully tested a QKD system over an outdoor free-space optical path of close to 1 km under nighttime conditions. Our results, which were reported in *Physical Review Letters*[7], show that free-space QKD can provide secure, real-time key distribution between parties who need to communicate secretly. This has definite practical advantages over fiber optic systems, making QKD a viable alternative for secure surface-to-satellite communications.

Demonstration and Results

The QKD transmitter in our demonstration (Fig. 1) consisted of a temperature controlled single-mode (SM) fiber pigtailed diode laser, a fiber to free-space launch system, a 2.5-nm bandwidth interference filter (IF), a variable optical attenuator, a polarizing beam splitter (PBS), a low-voltage Pockels cell, and a 27× beam expander. The diode laser wavelength was temperature-adjusted to 772 nm, and the laser was configured to emit a short pulse of approximately 1-ns duration, containing ~10^5 photons.

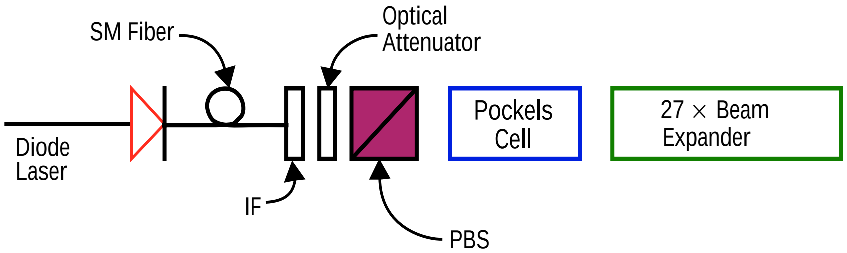

***Fig. 1** Diagram of our free-space QKD transmitter.*

In our QKD system, the sender, "Alice," starts by generating a secret random binary number sequence. Using a computer control system, Alice pulses the laser at a rate previously agreed upon between herself and the recipient, "Bob." Each laser pulse is launched into free space through the IF, and the pulse is then attenuated to an average of less than one photon per pulse, based on the assumption of a statistical Poisson distribution. The photons that are transmitted by the optical attenuator are then polarized by the PBS. Alice and Bob agree in advance on the polarization states that she will send, as well as those he will measure; their algorithm can be shared with the public without threatening the security of the system. In our demonstration, we used the B92 protocol.[8] The PBS was set to transmit an average of less than one horizontal-polarized photon, $|h>$, to the Pockels cell, and the Pockels cell was then randomly switched to either pass the light unchanged as $|h>$ (zero-wave retardation) or change it to a right-circular-polarized photon, $|r>$ (quarter-wave retardation).

The QKD receiver in our demonstration (Fig. 2) used an 8.9-cm Cassegrain telescope to collect the photons and direct them to the receiver optics and detectors. The receiver optics consisted of a 50/50 beam splitter (BS) that randomly directed the photons onto either of two distinct optical paths, each of which measures for one of the agreed-upon polarization states. One output port along each optical path was coupled by multimode (MM) fiber to a single-photon counting module (SPCM). Although the receiver did not include IFs, the spatial filtering provided by the MM fibers effectively reduced ambient background noise during nighttime operation (~1.1 kHz) to negligible levels. The lower optical path contained a polarization controller (a quarter-wave retarder and a halfwave retarder) followed by a PBS to test collected photons for $|h>$; the upper optical path contained a half-wave retarder followed by a PBS to test for $|r>$.

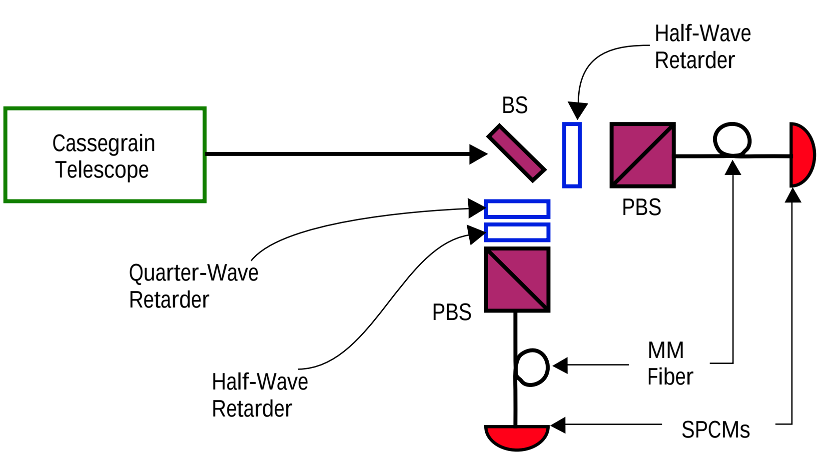

Fig. 2 Diagram of our free-space QKD receiver.

Note that Bob does not look for Alice's original states, but for related states. This ensures that Bob will never detect a photon for which he and Alice have used a preparation/measurement pair that corresponds to different bit values, which happens for 50% of the bits in Alice's sequence. For example, a single |*r*> photon traveling along the lower path encounters the polarization controller and is converted to |*v*> and reflected away from the SPCM by the PBS. Conversely, a single |*h*> photon traveling the same path is converted to |*r*> and transmitted toward or reflected away from the SPCM in this path with equal probability. Similarly, a single |*h*> photon traveling the upper path encounters a half-wave retarder and is converted to |*v*> and is reflected away from the SPCM in this path, but a single |*r*> photon traveling this path is converted to a left-circular-polarized photon, |*l*>, and transmitted toward or reflected away from the SPCM with equal probability. Thus, by detecting single photons, Bob identifies only a random 25% portion of the bits in Alice's random bit sequence, assuming a single photon Fock state with no bit loss in transmission or detection. This 25% efficiency factor is the price that Alice and Bob must pay for secrecy.

To complete the QKD procedure, Bob and Alice reconcile their common bits through a public discussion by revealing the locations, but not the bit values, in the sequence where Bob detected photons; Alice retains only those detected bits from her initial sequence. The resulting detected bit sequences comprise the raw key material from which a pure key is distilled using classical error detection techniques. Once Alice and Bob share this unique key, they can code, transmit, and decode messages securely.[7]

In our demonstration, we operated the transmitter and receiver optics over 240-, 500-, and 950-m outdoor optical paths under nighttime conditions with the transmitter and receiver collocated to simplify data acquisition. All optical paths were achieved by reflecting the emitted beam from a 25.4-cm mirror positioned at the halfway point of the transmission distance.

Results for the 950-m path showed a bit error rate (BER), defined as the ratio of the bits received in error to the total number of bits received, of ~1.5% when the system was operating at a level of ~0.1 photons per pulse (BERs of ~0.7% and ~1.5% were observed for the 240-m and 500-m optical paths, respectively). A sample of raw key material from the 950-m test, including errors, is shown in Fig. 3. Using narrow gated coincidence timing windows (~5 ns) and spatial filtering, we minimized the bit errors due to ambient

Sender's raw key:
1111111000000101010110111111100111111011110101001101001011101111
Receiver's ray key:
1111101000000101010110111111100011111011110101001101001011101111

Fig. 3 A sample of the sender's and receiver's raw key material, which was generated in our demonstration across a free-space distance of ~1 km. Only two errors, indicated in red, occurred during this transmission.

background to less than ~1 every 9 seconds. Further, because detector dark noise (~80 Hz) contributed only about one dark count every 125 seconds, we believe that the observed BER was mostly caused by misalignment and imperfections in the optical elements (wave plates and Pockels cell). While this BER surpasses even the BER attained with our fiber systems[2,3,4], any BER may potentially be caused by an eavesdropper. "Privacy amplification" must therefore be applied.[9]

Toward QKD for Satellite Communications

One of the goals of our demonstration was to evaluate the feasibility of conducting free-space QKD between a ground station and a satellite in a low-earth orbit. We designed our QKD system to operate at a wavelength of 772 nm, at which the atmospheric transmission from surface to space can be as high as 80%, and for which single-photon detectors with efficiencies as high as 65% are commercially available; at these optical wavelengths, atmospheric depolarizing effects are negligible, as is the amount of Faraday rotation experienced on a surface-to-satellite path.

To detect a single QKD photon it is necessary to know when it will arrive. The photon arrival time can be communicated to the receiver by using a bright precursor reference pulse. Received bright pulses allow the receiver to set a 1-ns time window within which to look for the QKD photon. This short time window reduces background photon counts dramatically. Background can be further reduced by using narrow bandwidth filters.

Atmospheric turbulence introduces beam wander, impacting the rate at which QKD photons would arrive at a satellite from a ground-station transmitter. The optical influence of turbulence is dominated by the lowest ~2 km of the atmosphere, the region in which our demonstration was conducted; the results of our 1-km experiment provide strong evidence that surface-to-satellite QKD will be feasible.

Assuming 30-cm diameter optics at both the transmitter and satellite receiver[7] and worst-case atmospheric "seeing" of 10 arc-seconds, we estimate that with a laser pulse rate of 10 MHz, an average of one photon per pulse, and atmospheric transmission of ~80%, photons would arrive at the collection optic at a rate of 800 to 10,000 Hz. Then, with a 65% detector efficiency, the 25% intrinsic efficiency of the B92 protocol, IFs with transmission efficiencies of ~70%, and a MM fiber collection efficiency of ~40%, a key generation rate of 35–450 Hz is feasible. With an adaptive beam tilt corrector, the key rate could be increased to about 3.5–45 kHz; these rates would double using the BB84 protocol.

Another challenge for surface-to-satellite QKD is the influence of ambient background. From our preliminary estimates of background photon rates during the full moon and new moon, we infer BERs of $\sim 9 \times 10^{-5}$ to 9×10^{-3} and $\sim 2 \times 10^{-6}$ to 3×10^{-5}, respectively. During daytime orbits the background radiance will be ~1% larger. We have recently demonstrated point-to-point, free-space QKD in daylight conditions. Results from initial tests have been positive, promising solutions to the challenge of distinguishing the single-photon signal in a bright background.

Already, our results show that QKD between a ground station and a low-earth orbit satellite should be possible on nighttime orbits, and possibly even in full daylight. During the several minutes that a satellite would be in view of the ground station there would be adequate time to generate tens of thousands of raw key bits, from which a shorter error-free key stream of several thousand bits would be produced after error correction and privacy amplification. If our tests in daylight conditions prove successful, it will remove the last great obstacle to this technology, ensuring that the promise of secure, surface-to-satellite communications becomes a reality.

References

[1] C. H. Bennett and G. Brassard, "Quantum Cryptography: Public Key Distribution and Coin Tossing," in *Proceedings of the IEEE International Conference on Computers, Systems, and Signal Processing, Bangalore, India* (IEEE, New York, 1984), p. 175.

[2] R. J. Hughes, D. M. Alde, P. Dyer, G. G. Luther, G. L. Morgan, and M. Schauer, "Quantum Cryptography," *Contemporary Physics* 36, 149 (1995).

[3] R. J. Hughes, *et al.*, "Quantum Cryptography Over Underground Optical Fibers," *Lecture Notes Computational Science* 1109, 329 (1996).

[4] R. J. Hughes, "Secure Communications using Quantum Cryptography," *SPIE Proceedings* 3076, 2 (1997).

[5] W. T. Buttler, R. J. Hughes, P. G. Kwiat, G. G. Luther, G. L. Morgan, J. E. Nordholt, C. G. Peterson, and C. M. Simmons, "Free-Space Quantum-Key Distribution," *Physical Review A* 57, 2379 (1998).

[6] B. C. Jacobs and J. D. Franson, "Quantum Cryptography in Free Space," *Optical Letters* 21, 1854 (1996).

[7] W. T. Buttler, R. J. Hughes, P. G. Kwiat, S. K. Lamoreaux, G. G. Luther, G. L. Morgan, J. E. Nordholt, C. G. Peterson, and C. M. Simmons, "Practical Free-Space Quantum Key Distribution Over 1 km," *Physical Review Letters* 81, 3283 (1998).

[8] C. H. Bennett, "Quantum Cryptography using any Two Nonorthogonal States," *Physical Review Letters* 68, 3121 (1992).

[9] C. H. Bennett, *et al.*, "Generalized Privacy Amplification," *IEEE Transactions on Information Theory* 41, 1915 (1995).

"Interaction-Free" Measurements: The In's and Out's of Quantum Interrogation

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For those of us familiar with quantum mechanics, it is common belief that a measurement on a system will necessarily disturb it (unless the system is already in an eigenstate of the measurement observable). This makes the concept of "interaction-free" measurements all the more intriguing. By incorporating the principle of complementarity and the "quantum Zeno effect," one can in fact achieve just such a measurement, in which the presence of an opaque object is determined optically, but with a negligibly small chance that the object absorbs or scatters any light in the process.

The idea was first proposed several years ago by Elitzur and Vaidman. They suggested using a simple interferometer, balanced so that an incident photon would always exit to a particular output port—the other port would remain dark due to complete destructive interference of the two paths in the interferometer; here a wave-like description is appropriate. However, the presence of an object in one arm will disrupt this interference. Now a particle-like description is more appropriate to account for the distinguishable trajectories of the photon. At the first beamsplitter, the photon has a 50% probability to take the path containing the object and be absorbed. But half the time the photon will take the other path; moreover, at the second beamsplitter, there is no longer any interference, so the photon will have a net 25% chance of going to the previously dark port. A "click" at the detector in this port unambiguously indicates the presence of the object, even though the photon could not have taken the path containing the detector (for then it would have been absorbed). Such measurements were termed "interaction-free," although the *possibility* of an interaction is crucial.

We have modified the basic idea of Elitzur and Vaidman to incorporate the possibility of *imaging*. A schematic of our setup is shown in Fig. 1. A photon polarized at 45° is incident on a polarizing Mach-Zehnder interferometer. The first polarizing beamsplitter transmits the horizontal component of the light and reflects the vertical component. These two are then recombined at the second polarizing beamsplitter. The polarization of the light is then measured in the 45/-45° basis. If the two paths are unimpeded and the path lengths are the same, then the light will still be polarized at 45°. If, on the other hand, there is an object in the vertical-polarization arm, then any light leaving the interferometer will be horizontally polarized, and hence will have a 25% chance of being detected by the -45° detector, an "interaction-free" quantum interrogation. By including a focusing lens before the interferometer and a similar collecting lens after it, we were able to create a small beam waist, through which we scanned a variety of ~one-dimensional objects, such as hairs, wires, optical fibers, *etc.* A typical example is shown in Fig. 2. With this system we were able to achieve a resolution of about 10 μm.

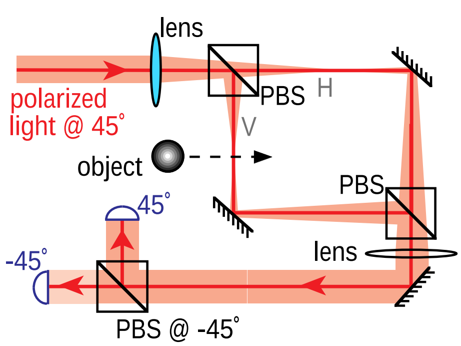


***Fig. 1** Schematic of experimental setup to demonstrate the principle of "interaction-free" measurements, modified to allow one-dimensional imaging.*

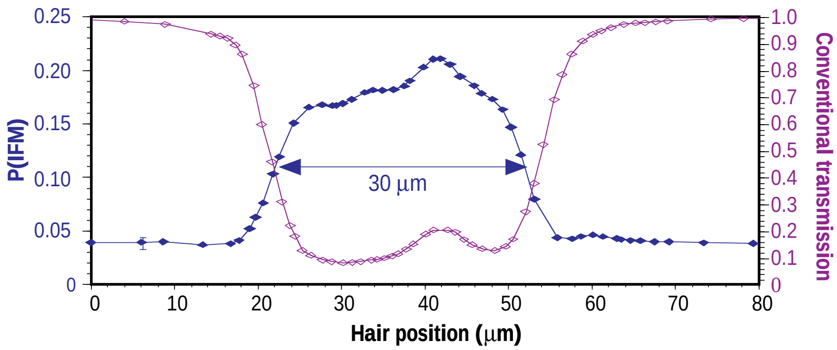


Fig. 2 Scan of a hair through the system shown in Fig. 1. The open purple symbols are a standard measurement of the hair transmission; the filled blue symbols are the "interaction-free" profile of the hair.

One immediate problem of the system proposed by Elitzur and Vaidman is that the object still absorbs the photon some fraction of the time. In fact, by varying the reflectivities of the interferometer beamsplitters (or by varying the input and analysis polarization in our imaging setup), one can affect the efficiency of the technique (see Fig. 3). Nevertheless, one can never get an efficiency over 50%, *i.e.*, at most half of the measurements will be "interaction-free."

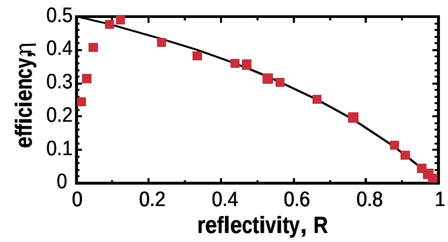


Fig. 3 The measured efficiency of the Elitzur-Vaidman technique as the effective reflectivity of the beamsplitters is varied. The solid curve is the theoretical prediction. The deviation of the experimental results for small reflectivities is due to unavoidable "crosstalk" in the polarizing beamsplitters (i.e., *a small amount of horizontally-polarized light is reflected).*

Along with collaborators at the University of Innsbruck in Austria, we have discovered a way in which one can in principle achieve efficiencies arbitrarily close to 1 (*i.e.*, the probability of absorption by the object can be arbitrarily small). A new quantum phenomenon must be utilized, namely the Quantum Zeno effect. A simple optical example is shown in Fig. 4a. A single horizontally-polarized photon is directed through a series of N polarization rotators (for concreteness we could imagine using an optically-active sugar solution), each of which rotates the polarization by $\Delta\theta = \pi/2N$; thus upon exiting the system, the photon now has

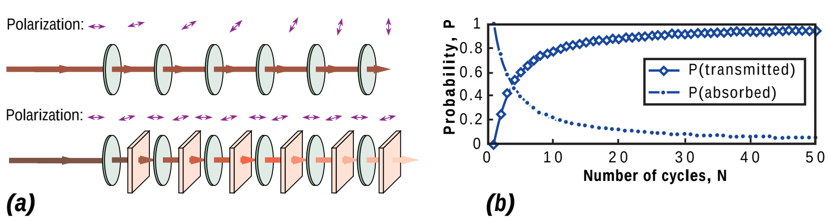


Fig. 4 (a) The quantum Zeno effect. In the top image, a single photon with horizontal polarization is rotated stepwise to vertical by a series of polarization rotators (green disks). The bottom image shows how this quantum evolution may be inhibited by interspersing a series of horizontal polarizers (red squares), which continually project the photon back into its original state. (b) Calculated probabilities of transmission and absorption through the system, as a function of the number of cycles.

vertical polarization. We may inhibit this stepwise evolution by making a measurement of the polarization at each stage. This may be accomplished by inserting a horizontal polarizer after each rotation element. Since the probability of being transmitted through each polarizer is just $\cos^2(\Delta\theta)$, the probability of being transmitted through all N of them is simply

$$\cos^{2N}(\Delta\theta) = \cos^{2N}(\pi/2N) \approx 1 - \pi^2/4N,$$

and the complementary probability of absorption is $P(abs) \approx \pi^2/4N$ (see Fig. 4b). Hence, by increasing the number of cycles, one can in principle have an arbitrarily small probability that the photon is absorbed by one of the polarizers, and yet, because the photon exits the system still in its initial horizontal polarization state, we know the polarizers are present.

Obviously the system from Fig. 4a is of limited use because it only works with polarizing objects. To be able to make a quantum interrogation of *any* nontransmitting object, one needs a hybrid solution. We have developed and tested such a system. The basic concept is shown in Fig. 5. A single photon is made to circulate N times through the setup before it is somehow removed and its polarization analyzed. As in the Zeno example, the photon initially has horizontal polarization, and is rotated by $90°/N$ on each passage through the rotator. In the absence of any object, the polarization-interferometer has absolutely no effect on the polarization of the light; it merely breaks the light into its horizontal and vertical components and adds them back with the same relative phase. Hence, if there is no object, after N cycles the photon is found to have vertical polarization. On the other hand, if there *is* an object in the vertical arm of the interferometer, only the horizontal component of the light is passed, *i.e.*, each *non*absorption by the object—with probability $\cos^2(\Delta\theta)$—projects the wavefunction back into its initial state. In this case, after N cycles, either the photon will still have horizontal polarization, unambiguously indicating the presence of the object, or the object will have absorbed the photon. And by going to higher N, the probability of absorption can in principle be made arbitrarily small.

To demonstrate this phenomenon in an actual experiment, several modifications were made (see Fig. 6). First, a horizontally-polarized pulsed laser was coupled into the system by a highly reflective mirror. The light was attenuated so that the average photon number per pulse after the mirror was only ~0.3. The photon then bounced several times between this recycling mirror and one of the mirrors making up a Michelson polarization interferometer (like a normal Michelson interferometer, but with a polarizing

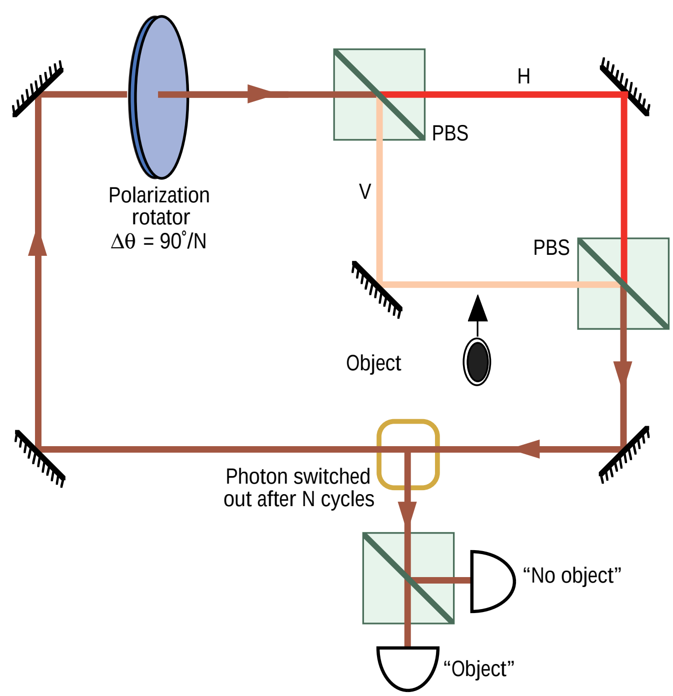


***Fig. 5** Simplified schematic of a hybrid system, combining the quantum Zeno effect with a polarization interferometer to allow >50% efficient interaction-free measurements.*

beamsplitter instead). At each cycle the polarization was rotated by a specific amount, and after the desired number of cycles the photon was switched out of the system using the high-voltage Pockel's cells in the interferometer arms. The photon was then analyzed using an adjustable polarizer, and detected by a single-photon detector. In the absence of any object in the vertical arm of the interferometer, the polarization was found to be essentially vertical, indicating that the stepwise rotation of polarization had taken place. In the presence of the object, this evolution was inhibited, and the photons exiting the system were still horizontally-polarized, an interaction-free measurement of the presence of the object. The fraction of measurements that were interaction-free was measured as the number of cycles N was increased (and the rotation angle, $\Delta\theta$, was correspondingly decreased).

Rather unexpectedly, we found that after an initial increase in efficiency, the efficiency actually decreased toward zero past some optimal number of cycles. A detailed theoretical calculation verified that this decrease arises due to loss in the system: basically, a photon that makes it to the detector experiences the single-cycle loss N times, while a photon that is absorbed by the object (which may happen at any cycle), experiences this loss only $\sim N/2$ times. The net effect is to reduce the efficiency for high-cycle numbers

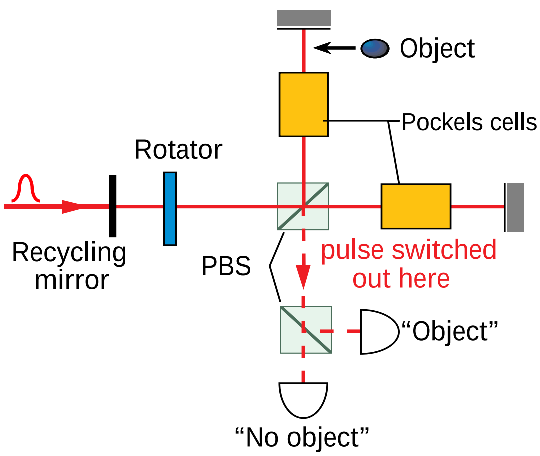
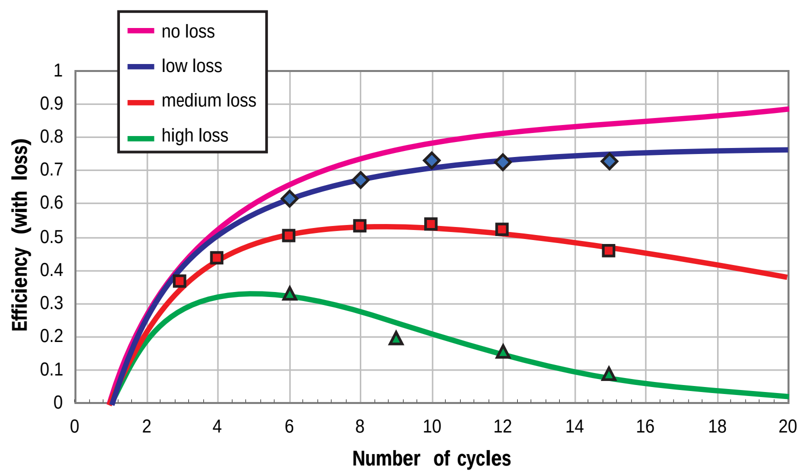


***Fig. 6** Experimental setup to demonstrate high-efficiency quantum interrogation. A photon remains in the system for N cycles, at which time the Pockel's cells are activated and the light is switched out. The polarization of the exiting photons depends on whether or not an object is blocking the vertical-polarization arm of the interferometer.*

rather than having it asymptote to 1. Figure 7 shows the experimental verification of this phenomenon, as well as the theoretical predictions, which are in good agreement. Despite this effect, we were able to observe efficiencies of up to 73%, which means that the presence of the object could be ascertained with only one-fourth of a photon being absorbed. Ours was the first measurement to break the 50% limit of the simple Elitzur-Vaidman technique. In addition, we have made measurements which confirm the feasibility of efficiencies up to 85%. And we now think we have a method to improve our system so that the probability of absorption could be as low as 1–2%. If these methods could be combined with the imaging techniques already explored, one would have a very useful tool for noninvasive diagnostics, *e.g.*, of delicate biological specimens or even photosensitive chemical reactions.

Another very interesting area we are studying is the possibility of making such quantum interrogations of truly quantum mechanical objects, such as single atoms or ions. The advantage of this is that the quantum object can be readily prepared into a superposition of states, one of which is sensitive to the "interaction-free" measurement technique, and one of which is not. Theoretical calculations predict that the state of the light and the state of the object will then become quantum mechanically *entangled*. Remarkably, it seems that this will be true even for light pulses containing several photons. If the object were measured to be in its

Fig. 7 Plot of experimentally measured efficiency versus number of cycles for several different values of loss.



initial state, one would then have a multiphoton pulse of light, in a superposition of horizontal and vertical polarization. This is an example of a Schrödinger cat and would open the door to a whole range of fundamental experiments on the nature of decoherence. It would also help to answer the question of why we do not observe macroscopic quantum superpositions in our everyday lives, even though we believe that quantum mechanics is a correct description of nature. One practical application of these interaction-free measurements of quantum objects is as a sort of quantum "interface" for connecting together different quantum computers (a separate research highlight addresses our contributions to quantum computation).

Further Reading

P. G. Kwiat, "Experimental and Theoretical Progress in Interaction-Free Measurements," *Physica Scripta* T76, 115 (1998).

P. G. Kwiat, H. Weinfurter, T. Herzog, A. Zeilinger, and M. A. Kasevich, "Interaction-Free Measurement," *Physical Review Letters* 74, 4763 (1995).

P. G. Kwiat, H. Weinfurter, and A. Zeilinger, "Interaction-Free Measurement of a Quantum Object: On the Breeding of 'Schrödinger Cats,'" in *Coherence and Quantum Optics VII*, J. Eberly, L. Mandel, and E. Wolf, Eds. (Plenum Publishing, 1996).

P. G. Kwiat, H. Weinfurter, and A. Zeilinger, "Quantum Seeing in the Dark," *Scientific American*, November 1996, pp. 52–58.

A. G. White, J. R. Mitchell, O. Nairz, and P. G. Kwiat, "'Interaction-Free' Imaging," *Physical Review A* 58, 605 (1998).

Plasma Source Ion Implantation Research, Development, and Applications

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Introduction

Plasma Source Ion Implantation (PSII) is a room temperature, plasma-based, surface enhancement technology that uses an ionized gas surrounding a target and high-negative-voltage, high-current pulses to accelerate ions into a target surface from all directions. Ion implantation can modify the target surface in beneficial ways, making it harder, reducing the coefficient of friction, and enhancing its resistance to corrosion.[1,2,3,4,5,6,7,8,9,10] These benefits are similar to those obtained through conventional ion beam implantation[11,12], but PSII differs from conventional techniques in several important aspects (see Fig. 1). First, ions are accelerated into the target through a plasma sheath[13] that surrounds the target, so the process is not “line-of-sight”—there is no requirement of an unobstructed path from a single ion source to the surface being treated. This allows PSII to treat multiple target surfaces and even multiple targets simultaneously without the need for in-vacuum manipulation of the target assembly. In addition, the average ion current to the target surface can be more than an order of magnitude larger than using conventional techniques[14,15,16], significantly reducing the required treatment time for large, complex target assemblies. This increase in average ion current is possible because nearly the entire target surface (potentially many square meters in area) can be treated simultaneously with a high pulsed-current source. Spreading the total applied current over a large surface area also tends to minimize local surface heating effects.

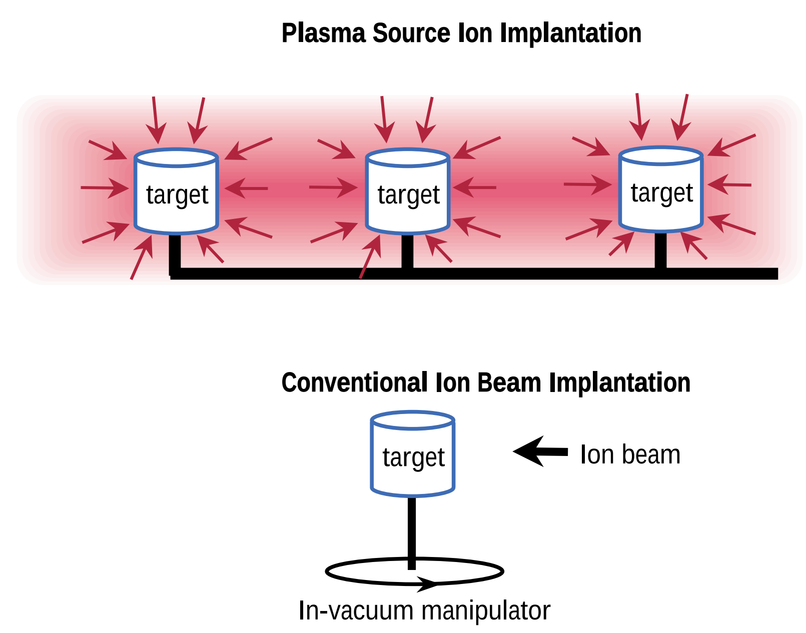

***Fig. 1** Schematic comparison of PSII and conventional ion beam implantation. PSII uses the plasma sheath to accelerate ions into the target (or multiple targets) from all directions. Conventional, accelerator-based ion implantation is a line-of-sight process, which requires in-vacuum manipulation of a target to implant complex surfaces.*

PSII was originally patented by John Conrad of the University of Wisconsin, Madison, and has been further developed and demonstrated at industrially relevant scales by researchers at Los Alamos in collaboration with the University of Wisconsin and General Motors Research. This technique is currently being commercialized through the efforts of General Motors, Asea Brown Boveri, Litton Electron Devices, Nano Instruments, Diversified

Fig. 2 The Los Alamos team participating in development and commercialization of PSII included (from left to right) Carter Munson, Michael Nastasi, Donald Rej, Jay Scheuer, Blake Wood, Kevin Walter, Ricky Faehl, and Ivars Henins. Team members not pictured include William Reass, Darrell Roybal, and Jose Garcia.

Technologies, Ionex, PVI, Empire Hard Chrome, A. O. Smith, Harley-Davidson, Kwikset, Boeing, and DuPont, as well as Los Alamos National Laboratory and the University of Wisconsin at Madison in a National Institute of Standards and Technology Advanced Technology Program project managed by the Environmental Institute of Michigan, Ann Arbor. The success of this research and development (R&D) effort earned an R&D 100 award from *R&D Magazine* in 1996 (Fig. 2).

There are several key factors that must be considered to successfully design and operate a commercial PSII system. These include the surface material science, overall vacuum system design, plasma source requirements, plasma-target interaction considerations, pulsed high-voltage subsystem (modulator) requirements, and target requirements and limitations. Critical system components are outlined in Fig. 3. This research highlight will focus on several important plasma physics effects related to the plasma-target interaction, particularly in the case of large, complex, multiple-component, target assemblies.

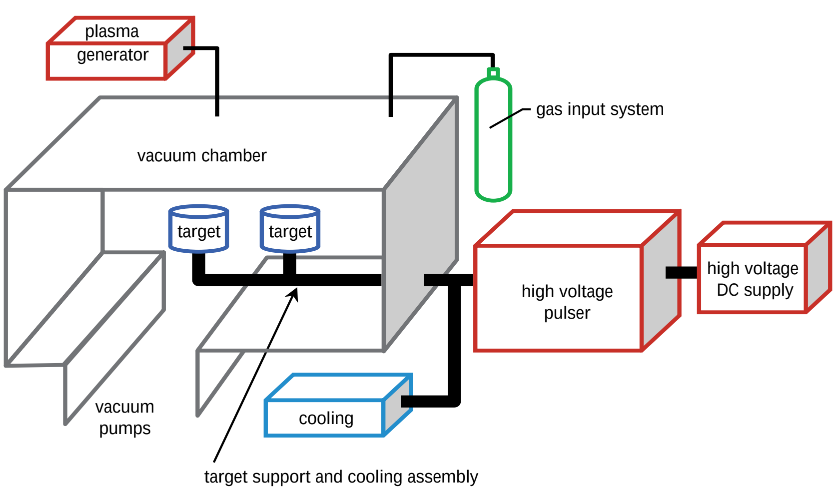

Fig. 3 Block diagram of a typical PSII system. Major system components include the vacuum chamber, pumping system, high voltage DC power supply, high voltage pulser or modulator, cooling system, target support assembly, plasma generation system, and working gas input system.

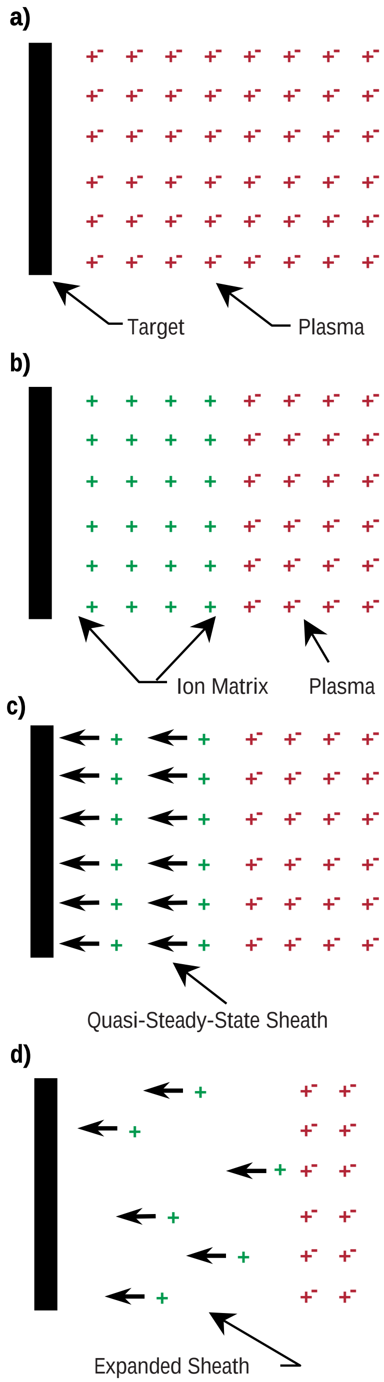

***Fig. 4** Plasma sheath temporal behavior for a planar target. Shown are the initial configuration with nearly uniform plasma surrounding the target (a), the formation of the ion matrix after electrons have been excluded from the region close to the target (b), ions accelerating through the sheath region into the target surface (c), and the expanded sheath late in the voltage pulse (d).*

Basic Plasma Sheath Physics

During the PSII process, a negative high voltage pulse is applied to create a transient plasma sheath[17,18,19] around the target and accelerate ions into the target surface. The characteristics of the plasma sheath play a major role in the PSII process. The fundamental evolution of the plasma sheath is illustrated in Fig. 4. In simple configurations (uniform plasma density and geometrically simple targets) the dimensions of the sheath are determined primarily by the initial plasma density, the voltage applied to the target, and the duration of the voltage pulse. In the basic initial configuration (Fig. 4a) a nearly uniform plasma surrounds the target. The great difference in mass between the electrons and ions in the plasma causes the electrons to move rapidly away from the target during the early portion of the voltage pulse, exposing plasma ions (Fig. 4b). The electric field established in the sheath region accelerates ions into the target (Fig. 4c). As ions are implanted into the target and lost from the sheath, the sheath edge recedes from the target (Fig. 4d). The sheath thickness increases during this time. Eventually, the sheath edge will extend to the vacuum chamber wall, or arcing will occur, limiting the useful pulse duration for implantation. Typical pulse widths, therefore, range from several microseconds to almost 100 µs.

From the fundamental equations describing the sheath evolution, it is clear that higher initial plasma densities result in smaller sheaths. Sheath dimensions that are small compared to the scale size of important target features result in more uniform implantation of the critical target surfaces, but require larger currents from the modulator.

Plasma Sheath and Target Interactions

A serious factor affecting PSII's commercial success is the production of secondary electrons.[8] Secondary electrons are produced when plasma ions impact the target surface, with each high-energy (many keV) ion potentially displacing a large number of electrons upon impact. For an aluminum target biased to 40 kV, as many as 19 secondary electrons are produced by each ion.[20] This would indicate an ion implantation efficiency of only 5% for the PSII process, since the total current that must be supplied by the modulator is composed of both the ion and secondary electron currents.

Under certain circumstances, the secondary electrons, rather than being a nuisance, may actually enhance the plasma discharge. The secondary electrons are repelled by the strong negative potential of the target and are accelerated to high energy in their outward passage through the sheath surrounding the target. When multiple, large, complex target assemblies are being treated with PSII, secondary electrons emitted by one portion of the target may be reflected from the sheath edge associated with other portions of the target surface, resulting in an increase in the residence time of the secondaries in the plasma. A larger portion of the energy of the

Fig. 5 Image of the target assembly consisting of ~1,000 piston surrogates in a background argon plasma.

secondary electrons is then deposited into the plasma, producing increased ionization and higher plasma densities than could be achieved without the secondaries.

Figure 5 shows the target assembly used in our experiments immersed in a background plasma. The assembly consists of four vertical racks consisting of 504 cylindrical targets (surrogates for aluminum automotive pistons). Each surrogate piston is a 5.08-cm-long section of 8.25-cm-diameter aluminum alloy tubing. The surrogate pistons are mounted lengthwise in pairs with a thin aluminum cap on each end. Fig. 6 shows a schematic of the arrangement. The cylinders can be packed tightly in the racks because only the sides need to be treated. The cylinder pairs are separated horizontally by 0.75-cm gaps, and vertically by ~1.1 cm of support structure and copper cooling lines. The total exposed area is over 16 m^2. The racks are spaced 25 cm apart and centered in a cylindrical vacuum chamber that is 1.5 m in diameter and 4.6 m long. The racks are supported by ceramic insulators and are connected to the high-voltage feedthrough by a manifold constructed from stainless steel tubing. A cooling fluid runs through the target assembly to remove energy deposited by the implantation process and limit the target's temperature excursion.

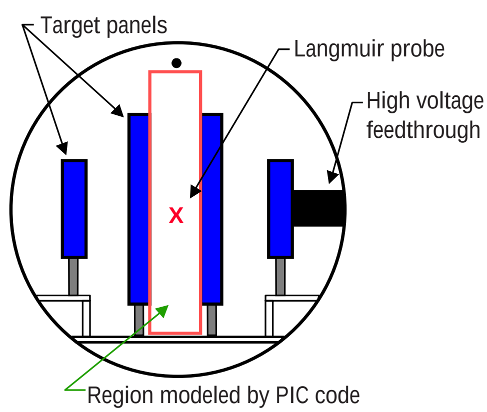

Fig. 6 Schematic of the piston surrogate assembly, vacuum chamber, and Langmuir probe insertion position (shown by an "X" in the figure).

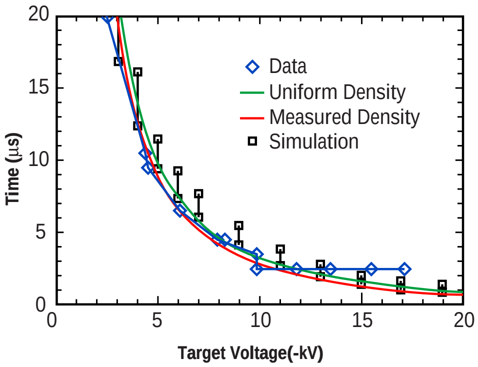

Fig. 7 Sheath overlap times between the racks of pistons as a function of target voltage. The blue data points were measured with the center probe tip. The green line is from the Lieberman theory for uniform density plasma, and the red line is for a parabolic density profile. The black squares are from the simulation, showing the finite time for the electron density to drop to zero.

To produce the background plasma, two 3 × 350-cm stainless steel radio frequency (RF) antennas are situated ~20 cm from the top of the vacuum chamber. One is centered and the other is displaced approximately 30° from vertical. A separate 1000-W, 13.56-MHz RF generator and matching network drives each antenna. The two RF generators are phase-locked, and are operated at the same power output setting. Driving the antennas creates a capacitive RF discharge of density $n \sim 10^8$ to 10^9 cm^{-3}, with an estimated electron temperature, T_e, of ~3 eV.[13] The electron distribution is not expected to be entirely Maxwellian, and probably contains a high energy tail.[21] In conventional systems, methane (CH_4) is typically used as a working gas during the ion implantation step of making a diamond-like-carbon coating.[10] However, we used argon as the working gas to reduce complications from multiple ionic species and time-dependent surface conditions of Langmuir probe tips. Argon fill pressures used in these experiments ranged from 20 to 65 mPa.

A Langmuir probe assembly was inserted axially into the vacuum chamber and positioned between the two center racks (Fig. 6). The probe assembly was used to monitor basic plasma parameters, primarily plasma density, floating potential, and indications of plasma fluctuations. The probe was also used to determine the spatial characteristics of the plasma sheath expansion within the target assembly. To clarify the experimental results, the central portion of the target assembly was modeled using a two dimensional particle-in-cell (PIC) computer code (XPDP2, obtained from the Plasma Theory and Simulation Group at the University of California in Berkeley). The experimental configuration and modeling efforts are described in detail in two recent publications[22,23] and are summarized below.

In the interior portion of the assembly, the target racks appear essentially as quasi-planar structures and generate roughly planar plasma sheaths. If plasma density, applied target voltage, and voltage pulse duration are in the appropriate range (moderate plasma density, applied target voltages above a few kV, and pulse durations in excess of a few microseconds), these sheaths expand outward from the target racks and collide with each other on the planes dividing the racks. Measurements obtained from the Langmuir probe assembly allow a direct determination of the sheath overlap time (referenced to the start of the voltage pulse) for various experimental conditions. These measurements have been compared with sheath overlap times calculated from simple analytic theory, from a modification of the standard analytic theory to account for the measured variation of the plasma density in the sheath expansion region, and from results of the numerical PIC code. The comparison of these results is shown in Fig. 7. In general, the agreement is fairly good for the set of conditions of this measurement set. These conditions, however, minimize the impact of the secondary electrons on the background plasma and sheath propagation characteristics.

The strong interaction of the secondary electrons, target assembly, and background plasma appears in the form of two different instabilities. The first, the “hollow cathode” instability, operates in much the same way as a hollow cathode discharge. Secondary electrons are temporarily trapped in the potential well between the racks of pistons, and directly ionize the background gas. The cross-section for ionization is enhanced by a reduction in the kinetic energy of the secondaries due to the overlap of the sheaths from adjacent racks of pistons so that this instability has significant impact only at low plasma densities and relatively high gas pressures. Furthermore, it occurs only if the secondary electron flux is sufficiently high. In experiments where a layer of graphite on the racks of pistons reduced the secondary electron emission coefficient, the instability was not observed until the graphite was sputtered off of the pistons. The hollow cathode instability effects are shown in Fig. 8.

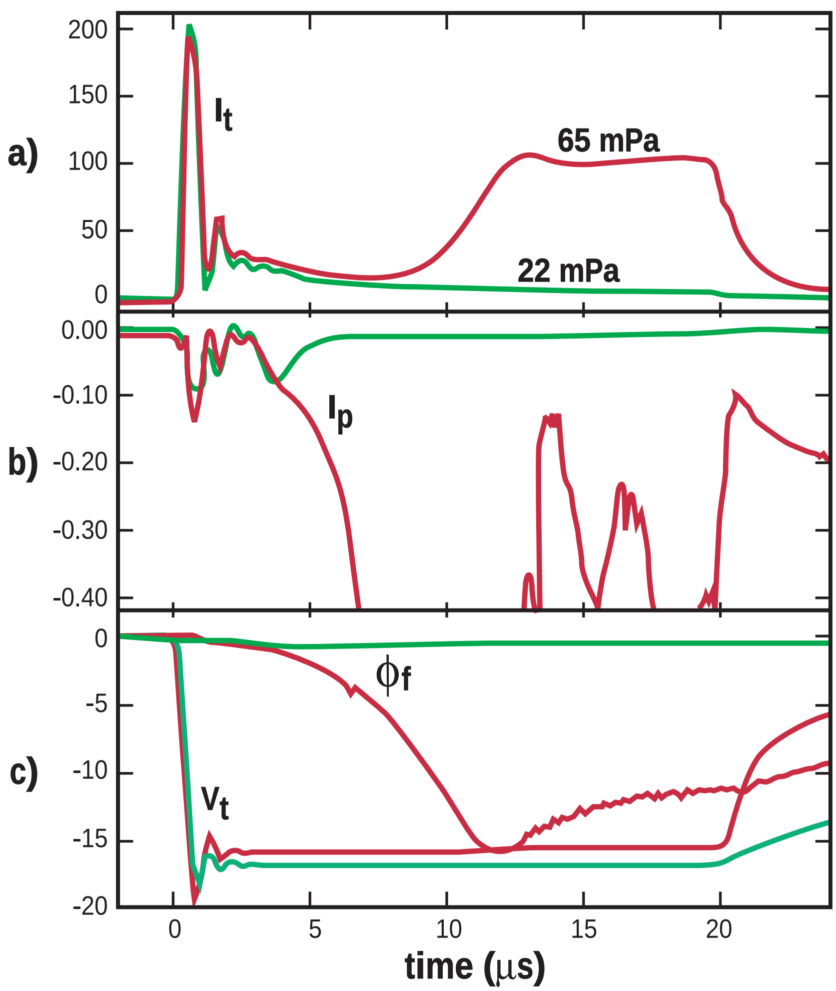

Fig. 8 Measurements of the (a) target current, I_t; (b) probe current, I_p; and (c) probe floating potential, ϕ_f, and target voltage, V_t, during the hollow cathode instability for 100 W of radio-frequency power. Negative currents signify the collection of electrons. The instability appears at 65 mPa fill pressure (red lines) but not at 22 mPa (green lines).

The second interaction mechanism is a beam-plasma instability, where the secondary electrons resonantly excite plasma waves. The energy in the plasma waves is transferred to the bulk plasma through Landau damping, causing an increase in the electron temperature and thereby an increase in the ionization rate. (A similar concept has been patented, but no experimental results have been published.) Unlike the hollow cathode instability, the beam-plasma instability requires a relatively large initial density. If the initial density is sufficiently large, the energy of the secondary electrons can be transferred to the bulk electrons before sheath overlap. The subsequent ionization of the background gas is then so rapid that the sheath motion is halted, preventing the sheaths from overlapping. A relatively high neutral gas pressure and a large flux of secondary electrons are also requirements for this instability to take hold. Impact of beam instability is illustrated in Fig. 9.

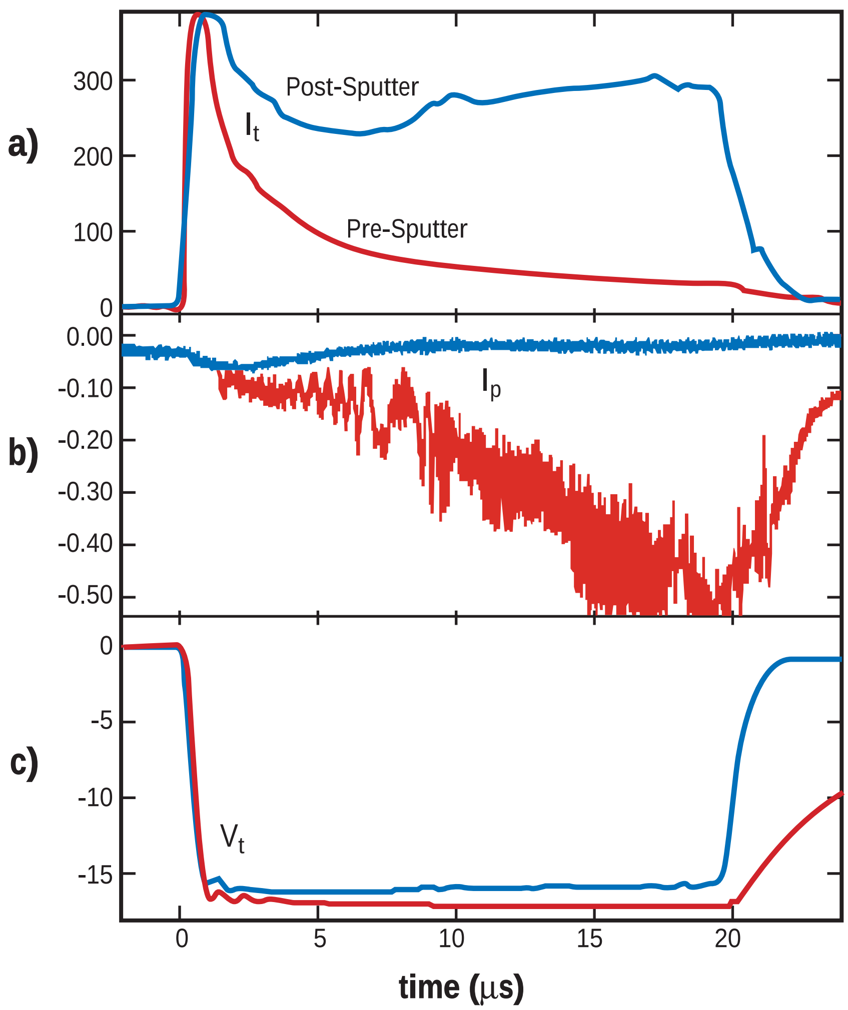

***Fig. 9** Measurements of the (a) target current, I_t; (b) probe current, I_p; and (c) target voltage, V_t, during the beam-plasma instability for 1,800 W of radio-frequency power and a gas pressure of 65 mPa. Negative currents signify the collection of electrons. The instability appears after sputter cleaning has increased the secondary electron flux (blue lines) but not before (red lines).*

Conclusions

Successful commercial application of PSII depends on the ability to appropriately implant target components in a wide range of geometric configurations, particularly those in which the components have been relatively densely packed into a processing chamber. In our experiment, we explored the plasma sheath and plasma-target interaction characteristics within such a complex target assembly. This study yielded the first experimental demonstration of several important interaction mechanisms which are driven in the geometrically complex PSII system by the presence of energetic secondary electrons generated at the target surface by the implanted ions. Understanding these interactions will significantly increase our ability to predict the behavior of complex targets, and optimize target configurations for commercial application of PSII technology.

References

[1] R. J. Adler and S. T. Picraux, "Repetitively Pulsed Metal-Ion Beams for Ion Implantation," *Nuclear Instruments and Methods in Physics Research B* 6, 123 (1985).

[2] J. R. Conrad and K. Sridharan (Eds.), "Papers from the First International Workshop on Plasma-Based Ion Implantation: August 4–6, 1993, University of Wisconsin," *Journal of Vacuum Science and Technology B* 12, 813 (1994).

[3] G. A. Collins (Ed.), "Proceedings of the Second International Workshop on Plasma-Based Ion Implantation, Sydney, Australia, February 12-15, 1995," *Surface Coatings and Technology* 85, 28 (1996).

[4] J. R. Conrad, "Sheath Thickness and Potential Profiles of Ion-Matrix Sheaths for Cylindrical and Spherical Electrodes," *Journal of Applied Physics* 62, 777 (1987).

[5] J. R. Conrad, J. L. Radtke, R. A. Dodd, F. J. Worzla, and N. C. Tran, "Plasma Source Ion Implantation Technique for Surface Modification of Materials," *Journal of Applied Physics* 62, 4591 (1987).

[6] J. R. Conrad, "Method and Apparatus for Plasma Source Ion Implantation," U.S. Patent No. 4,764,394 (August 16, 1988).

[7] J. R. Conrad, "Plasma Source Ion Implantation: A New Approach to Ion-Beam Modification of Materials," *Materials Science and Engineering A* 116, 197 (1989).

[8] D. J. Rej and R. B. Alexander, "Cost Estimates for Commercial Plasma Source Ion Implantation," *Journal of Vacuum Science and Technology B* 12, 2380 (1994).

[9] D. J. Rej, "Plasma Source Ion Implantation," in M. Nastasi and J. W. Mayer (eds.), *Ion-Solid Interactions: Fundamentals and Applications*, Vol. I (Cambridge University Press, New York, 1996), p. 467.

[10] C. P. Munson, R. J. Faehl, F. Henins, M. Nastasi, W. A. Reass, D. J. Rej, J. T. Scheuer, K. C. Walter, and B. P. Wood, "Recent Advances in Plasma Source Ion Implantation at Los Alamos National Laboratory," *Surface and Coatings Technology* 84, 528 (1996).

[11] R. B. Alexander, "Using Ion Implantation to Improve Forming-Tool Life," *The Fabricator* II, 1 (1992).

[12] A. Chen, J. T. Scheuer, C. Ritter, R. B. Alexander, and J. R. Conrad, "Comparison between Conventional and Plasma Source Ion-Implanted Femoral Knee Components," *Journal of Applied Physics* 70, 6757 (1991).

[13] M. A. Lieberman and A. J. Lichtenberg, *Principles of Plasma Discharges and Materials Processing* (Wiley-Interscience, New York, 1994).

[14] S. B. J. Charter, L. R. Thompson, and G. Dearnaley, "The Commercial Development of Ion Implantation for Steel and Carbide Tools," *Thin Solid Films* 84, 355 (1981).

[15] F. A. Smidt and D. B. Sartwell, "Manufacturing Technology Program to Develop a Production Ion Implantation Facility for Processing Bearings and Tools," *Nuclear Instruments and Methods in Physics Research B* 6, 70 (1985).

[16] J. R. Treglio, A. J. Perry, and R. J. Stinner, "Economics of Metal Ion Implantation," in *Proceedings of the Eighth International Conference on Surface Modification of Metals by Ion Beams* (September 1993, Kanazawa, Japan) *Surface and Coatings Technology* 65, 184 (1994).

[17] J. T. Scheuer, M. Shamim, and J. R. Conrad, "Model of Plasma Source Ion Implantation in Planar, Cylindrical, and Spherical Geometries," *Journal of Applied Physics* 67, 1241 (1990).

[18] J. G. Andrews and R. H. Varley, “Sheath Growth in a Low-Pressure Plasma,” *Physics of Fluids* 14, 339 (1971).

[19] B. P. Wood, “Displacement Current and Multiple-Pulse Effects in Plasma Source Ion Implantation,” *Journal of Applied Physics* 73, 4770 (1993).

[20] M. Shamim, J. T. Scheuer, R. P. Fetherston, and J. R. Conrad, “Measurement of Electron Emission due to Energetic Ion Bombardment in Plasma Source Ion Implantation,” *Journal of Applied Physics* 70, 4756 (1991).

[21] V. A. Godyak, R. B. Piejak, and B. M. Alexandrovich, “Probe Diagnostics of Non-Maxwellian Plasmas,” *Journal of Applied Physics* 73, 3657 (1993).

[22] B. P. Cluggish and C. P. Munson, “Sheath Overlap During Very Large-Scale Plasma Source Ion Implantation,” *Journal of Applied Physics* 84, 5937 (1998).

[23] B. P. Cluggish and C. P. Munson, “Secondary-Electron Enhanced Discharges in Plasma Source Ion Implantation,” *Journal of Applied Physics* 84, 5945 (1998).

Convergent Hydrodynamics of Inertial Confinement Fusion Implosions

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Introduction

The National Ignition Facility[1] (NIF), a large laser presently under construction at the Lawrence Livermore National Laboratory, is designed to produce 1.8 MJ of 0.35-μm light in a 500-TW pulse for defense applications and inertial fusion ignition. Although fundamental questions about the feasibility of achieving high gain in inertial fusion capsule implosions were settled a decade ago in a series of underground experiments at the Nevada Test Site, it remains a major scientific and technical challenge to obtain capsule ignition and gain in the laboratory with the laser energy and power available at the NIF.

Inertial fusion ignition and gain requires that a fuel region with enough size and density be heated to a high temperature such that fusion burn can be transiently sustained by energy deposited by the charged fusion reaction products. Ignition is easiest to obtain using a deuterium-tritium fuel mixture, and for this fuel the requirements are a temperature of about 20 keV and a density-radius product of a few g/cm^2. Rather than producing these conditions in a uniform volume (which would require a laser energy on the order of 100 MJ), the mainline capsule design for the NIF employs a concept known as "hot-spot" ignition. In this concept, a small fraction of the fuel mass is ignited in a central hot spot, and then a thermonuclear burn wave propagates outward into the surrounding compressed fuel to produce a significant fusion yield.[1]

Hydrodynamic perturbation growth during the capsule implosion plays a major role in determining whether the hot spot in the fuel can ignite. Hydrodynamic instabilities pose a threat to ignition by creating spikes of cold fuel that penetrate into the hot spot and increase thermal losses from this region. The energy required to ignite a capsule increases as shell thickness increases, and the minimum acceptable shell thickness depends on the magnitude of the perturbation growth that would disrupt the shell. Hydrodynamic instabilities can also reduce the efficiency with which the kinetic energy of the imploding shell (or "pusher") is converted to temperature of the hot spot and reduce the overall compression of the fuel. Another mechanism that could affect ignition is the introduction of contaminants from the shell into the fuel (a process known as "mix") and subsequent radiative energy loss.

Perturbations occur because of nonuniformities in the radiation drive on the shell or fuel surface. During the ablative acceleration phase, perturbations at the ablation front grow via the Rayleigh-Taylor instability, whereby the lower-density ablated material accelerates the higher-density unablated shell. These perturbations are transferred or "fed through" to the inner surface of the shell, where they can further grow during the convergence and deceleration phases (see Fig. 1). These inner surface perturbations cause mix of the cold ablator with the hot fuel, either preventing ignition or, conversely, increasing the size of the driver required to achieve a fixed gain.

Because the Rayleigh-Taylor instability at the ablation front is expected to be the dominant effect for inertial confinement fusion (ICF) implosions, there has been much effort devoted to theoretical development and measurement of the instability under ICF-relevant conditions. However, few experiments have explored the effects of ablatively driven Rayleigh-Taylor growth in convergent geometries. Calculations of the hydrodynamic performance of ignition capsules[2] for the NIF need to be validated by present-day experiments. To address this issue, the Laboratory's ICF Program has launched two campaigns to explore the growth of hydrodynamic instabilities in cylindrical and spherical geometries. This research highlight describes each of these research efforts with an overview of the results.

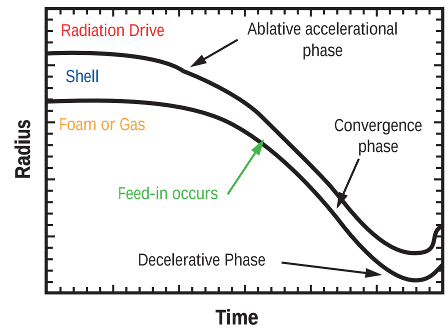


Fig. 1 Phases of hydrodynamic instability during an implosion. Perturbations on the outside of the shell are fed through to the inner surface, where they grow as the implosion progresses.

Cylindrical Implosion Research on the Ablative Rayleigh-Taylor Instability

Cylindrical implosions can provide physical insight into convergent hydrodynamics issues because cylindrical geometry allows for excellent diagnostic access along a line of sight and provides a good match to present two-dimensional (2-D) simulation codes. By contrast, in a spherical implosion along any diagnostic line of sight, material is moving towards, away from, and across the diagnostic. Unfolding the radial dependence of the implosion from such line-integrated observations is difficult. Thus, spherical implosion experiments usually rely on "integrated" measurements of the performance of the implosion. In a cylindrical implosion, the diagnostic view along the cylindrical axis only has material moving at right angles to the field of view and the radial unfolding of the information is straightforward. With proper design of the axial implosion, the experiment can be kept relatively 2-D and thus tractable for detailed comparison to present-generation simulation codes. Convergent effects are not as strong in a cylindrical implosion (only increasing as $1/R$ and not $1/R^2$ as in a spherical implosion), but those effects can still be effectively studied.

Our early research focussed on cylindrical implosions using indirect-drive at Livermore's Nova laser.[2,3] Experiments were conducted using a cylinder that extended transversely across the entire diameter of a Nova hohlraum, which was driven using eight Nova beams with a total energy of 22–25 kJ (Fig. 2). The eight beams were arranged symmetrically around the cylinder in the hohlraum to provide the best possible drive symmetry although there still was an initial $m = 4$ azimuthal variation of illumination. The implosions were radiographed axially using a gated x-ray pinhole imaging system and a silver or titanium backlighter foil on the far side.

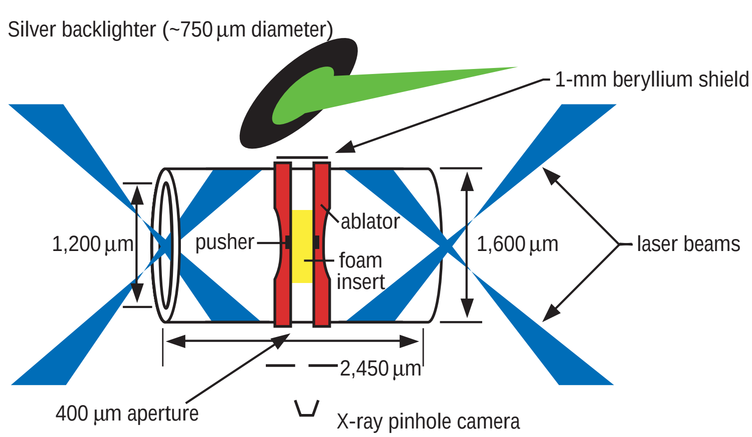


Fig. 2 Experimental design for an indirect-drive experiment on Nova. The cylinder is mounted transversely across the diameter of the hohlraum. Eight laser beams are arranged symmetrically around the cylinder and drive its implosion with an energy of 22–25 kJ. The x-ray pinhole imaging system (which includes the backlighter, beryllium shield, aperture, and pinhole camera) provides axial radiographs of the imploding cylinder.

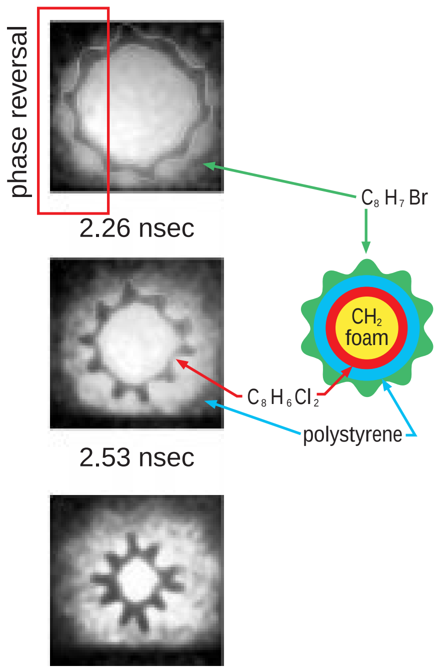


***Fig. 3** Sequence of gated x-ray framing camera images from an indirectly-driven cylindrical implosion at Nova. The dark, convoluted region comes from feed-in of perturbations growing at the ablation surface to a marker region of chlorinated plastic. The dark region at the outside is ablated brominated plastic. The lighter area between these layers is the polystyrene ablator. (Diagram of layers is not to scale.)*

The cylinder design primarily used in these experiments had a 472-µm outer diameter, and it comprised a brominated polystyrene ablator over a plain polystyrene pusher with a 60-mg/cc, 430-µm-inner-diameter, polystyrene foam insert. The cylinder was shielded by gold coating at its ends and was tapered along its length so that only an approximate 300-µm waist region imploded. The axial length was further defined by a thin, 160-µm-long chlorinated polystyrene marker layer between the pusher and the foam; however, further tests have confirmed that most of the radiographic contrast comes from radial densification of the implosion and not from the opacity of the chlorinated marker. Perturbations were machined azimuthally on the outside of the ablator.[4]

A sequence of over 20 targets was shot at Nova with nearly identical conditions. Only the azimuthal mode number (either m = 10 or m = 14) or amplitude (unperturbed, 0.25, 0.5, 1.0, 1.5, 3.0, and 5.0 µm) of the machined perturbation varied. (The mode number is the number of perturbation wavelengths around the circumference of the cylinder.) An example of the sequence of data provided from a single shot is shown in Fig. 3. These experiments provided valuable data for all three phases of instability growth during cylindrical implosions. There is a clear indication of phase reversal at the ablation surface (the outer dark region).

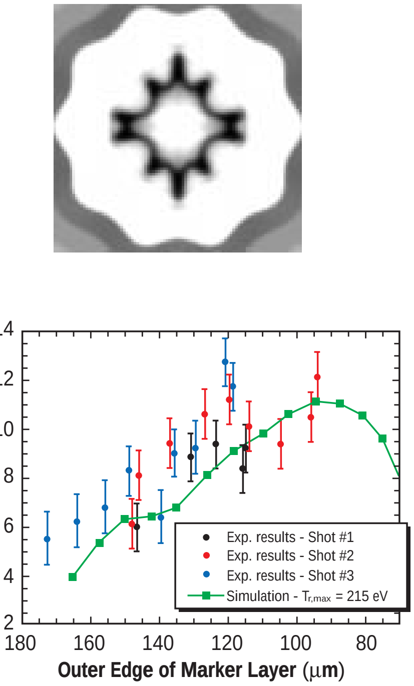
The first phase of the implosion consists of initial ablative Rayleigh-Taylor instability growth at the ablation front, in which the perturbations feed into the marker region (which has a higher compressed density at the plastic-foam interface). The ratio of the final measured perturbation amplitude and initial machined perturbation amplitude is the measured growth factor. In these initial indirect-drive experiments, the acceleration tended to occur only while the convergence ratio was less than about 1.5. The measurements of instability growth occur at or after the time this convergence is reached. Hence the ablative Rayleigh-Taylor instability growth sets the initial amplitude observed in the experiment. Our experiments confirm the expectation that the mode m = 14 grows faster and to higher amplitude than the m = 10. Perturbations with initial amplitude 1.5 µm or less remained linear during the ablative Rayleigh-Taylor phase, and the growth factors for the same mode number were the same during the entire implosion. Detailed time-dependent measurements of mode amplitudes can then be compared to hydrodynamic simulations. A post-processing code is used to simulate the x-ray radiographs from calculations with LASNEX, a 2-D radiation hydrodynamics code, using the same filtering and analysis as done in the experimental data reduction (see Fig. 4).

In the second phase, convergence, the perturbations continue to grow even in the absence of acceleration. This “crenulation” effect, first identified by Bell[5] and Plesset[6], is a feature of all convergent implosions that act incompressibly. For a ring or shell of material to maintain its volume as it converges, it must thicken and its wrinkles must grow. In our experiments, all of the perturbations appeared to grow at the same rate regardless of size, even when the perturbations exceeded usual “nonlinearity conditions” (*e.g.*, even when the amplitude was a significant fraction of the wavelength or radius). The largest initial amplitude perturbations did show signs of saturation in their growth, but not until they reached amplitudes divided by wavelength of nearly unity! Examples of the different nonlinear shapes that result from starting with increasing initial amplitude are shown in Fig. 5. These nonlinear effects were studied in detail using a target with the largest initial amplitude yet tried, an m = 10, 5-µm perturbation. This amplitude was chosen to go nonlinear during the ablative Rayleigh-Taylor phase. Several features are seen in these images. First, the rod-like spikes grew steeper and, for the first time in these experiments, developed observable harmonics of the fundamental. The image also shows that, late in time, the spikes "crush in" from the compressibility effects of Bell-Plesset growth.

During these first two phases of the implosion, there is second-order, weakly nonlinear mode coupling between the machined perturbations and the m = 4 illumination asymmetry caused by the eight laser beams in the hohlraum. This leads to m = 10 + 4 = 14 and m = 10 - 4 = 6 modes with phases and amplitudes that appear consistent (within factors of two) with theory[7] when derived for convergent geometry. This mode coupling creates the "lumpy" look of the data, which is not noise, but actually an important feature of the physics.

In the third phase, deceleration, there is expected to be Rayleigh-Taylor growth at the unstable pusher-foam interface. However, three-dimensional (3-D) end effects in the target design made the interface inside the marker layer diffuse and such effects were not seen. At the outside of the marker layer, compressibility effects[3] reduced the size of the perturbations.

To improve upon the Nova experiments, we collaborated with scientists from the University of Rochester on a series of experiments to study convergent hydrodynamics using direct-drive illumination at the Laboratory of Laser Energetics Omega facility.[8] The use of direct-drive illumination couples more energy into an implosion (perhaps 10 kJ out of 18 kJ of ultraviolet laser light instead of 3 kJ from the



(a)

(b)

Fig. 4 Post-processed simulation of an axial x-ray radiograph generated from a hydrodynamic simulation of an indirect-drive cylindrical implosion on Nova (the image includes m = 4 illumination asymmetry). (b) Comparison of simulated amplitude and experimental measurements from m=10, 1-µm initial amplitude perturbations. The simulations fit well with the experimental results.

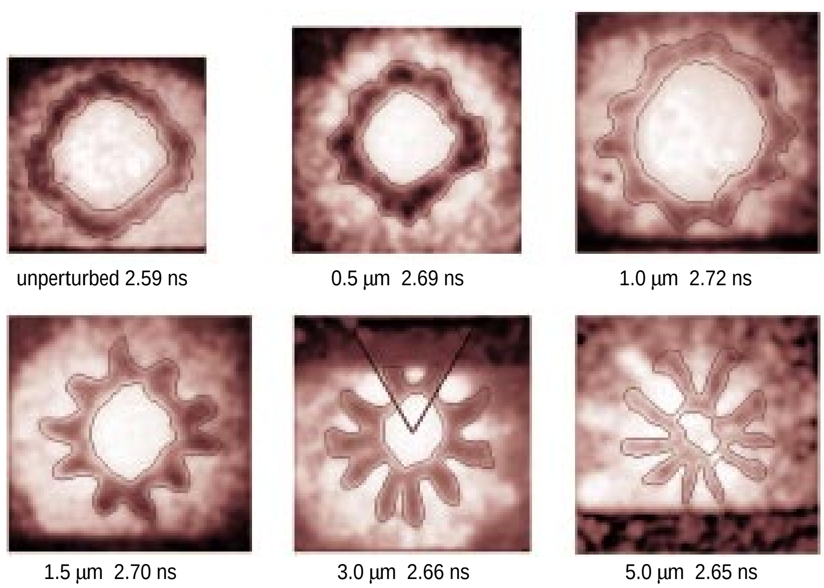


Fig. 5 Images at similar times (and hence radii) of cylindrical implosions, starting from different initial perturbation amplitudes. Varying the starting amplitude produces widely different nonlinear shapes.

Fig. 6 Photograph of the cylinder used in direct-drive experiments on Omega. The cylinder is aligned along the diagnostic axis and includes components of the imaging system (axial backlighter, leaded acrylic aperture, and various alignment fibers).

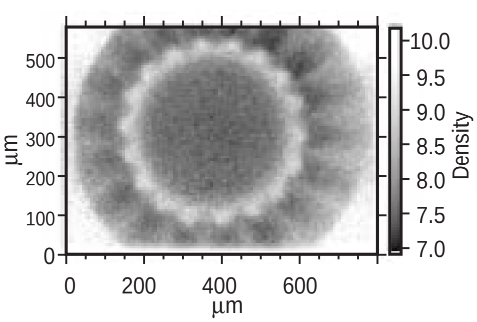


Fig. 7 X-ray radiograph from a "feed-out" test using direct-drive cylindrical implosion on Omega. The experiment used a cylinder with m = 18, 1.5-µm amplitude perturbations on the interior surface of the ablator. These perturbations "fed-out" to the ablation front and grew as the implosion progressed.

indirect-drive x-ray radiation for a similar amount of ultraviolet laser energy). Thus, we were able to implode cylinders that were twice as large as the ones used in the Nova experiments with corresponding increases in convergence ratio at maximum acceleration (2.5 instead of 1.5), growth factors (30 instead of 15), and resolution (nearly twice the pixel resolution elements at the same convergence). Using direct drive advances in smooth beam illumination (distributed phase plates and smoothing by spectral dispersion) we achieved generally more symmetric implosions with less mode coupling as well.[9]

The cylinders used in the Omega experiments (see Fig. 6) were unique because of their thin-wall construction. With an inside diameter of 860 µm and a wall of 20 µm, these polystyrene cylinders were particularly fragile. To ensure their survival, the polystyrene-coated mandrels were annealed three times prior to final mandrel removal. The outer surface of the cylinders was machined with azimuthal modes varying with m = 14, 28, 38, or 58, with amplitudes from 0.5 to 1 µm. The 2.25-mm-long plastic cylinders were coated with 500 Å of aluminum that served as a shine shield to provide uniform plasma breakdown. They were filled with 60 mg/cc polystyrene foam; some targets had the foam doped with deuterium or chlorine to enhance neutron or spectroscopic diagnostic measurements. Extensive metrology of the completed targets (measuring angles to within 0.1° and position to within a few µm) ensured that the Omega beams provided the illumination required and that all of the beams hit the target.

During the Omega experiments, 50 laser beams were focussed around a central band of the cylindrical target. Very symmetric implosions were achieved with convergence ratios of seven for the shell and 10 for the hot spot or axial emission spike. Twenty-two shots were obtained in this first scoping campaign, including 17 implosions, 15 of which had both excellent energy and power balance. Thirty-four shots were obtained in the second campaign including 28 implosions scoping out a variety of experimental and theoretical issues. On each shot, five to eight of the remaining laser beams were focussed on titanium backlighters. X-ray radiography was performed both axially and transverse to the cylinder axis to produce excellent sets of gated framing camera images of the hydrodynamics of the cylinder imploding.[10] Results from one experiment are shown in Fig. 7. In addition, framing and streaked images and time-resolved x-ray spectroscopy were used to explore the behavior of these targets.

During this campaign, we modified two of the target cylinders to allow for study of perturbations on the interior surface. The image in Fig. 7 shows an x-ray radiograph from this experiment. Perturbations with m = 18 and 1.5 µm amplitude were put on the inside surface of the ablator at the foam interface. The results from these interior perturbation experiments can be used to study the "feed-out" problem associated with the Rayleigh-Taylor instability.[11] In this process, the initial shock driven through the ablator reflects off the rippled surface at the inside and bounces back to the ablation front where it seeds instability growth there.

Detailed analysis of these experiments and design for future campaigns continues, now in additional collaboration with researchers from the Atomic Weapons Research Establishment in the United Kingdom and from the University of Florida. These results are providing high quality data useful for validation of complex hydrodynamic calculations such as those used to predict ignition at the NIF.[12] Figure 8 shows comparisons of measured mode amplitude with LASNEX simulations, showing disagreement late in the acceleration history with the predicted mode growth. Current work concentrates on understanding and ameliorating the effects of short-wavelength laser nonuniformities on the perturbation growth; measuring the "thermodynamics" of the cylindrical implosions by spectroscopic or neutronic methods for comparison to the observed hydrodynamics; and observing mix and defect evolution at the inside interface of the ablator.

Spherical Capsule Implosions using a Deuterated Layer

While experiments such as those described above provide useful information about perturbation growth, ignition capsules designed for the NIF are, in general, much more unstable than cylindrical (and most spherical) implosions studied in Nova and Omega experiments. In the absence of nonlinear effects that reduce the perturbation growth rate, the spikes of cold pusher material penetrating into the hot-spot region of these NIF capsules are predicted to be ~400-times larger than the initial perturbations on the capsule surfaces (this is known as the linear growth factor). Fortunately, nonlinear processes reduce the perturbation growth and thus the size of the spikes. In order to test the ability of our computer simulations to predict the *actual* levels of perturbation growth in NIF capsules, a series of spherical capsule implosions on Nova was designed to maximize the perturbation growth and produce linear growth factors at levels as close as possible to those expected in ignition capsules on NIF.

These high-growth Nova implosions, designed by Keane[13] and performed by Hammel and Landen[14], enhanced the perturbation growth by using a germanium dopant in the pusher, producing linear growth factors of ~100. The main diagnostic of capsule performance was the neutron yield from deuterium gas filling the capsule (Fig. 9a). In these Nova implosions, the three deleterious effects of perturbation growth (enhanced thermal losses, mix, and reduced compressional heating) all act to cool the deuterium fuel so that their relative

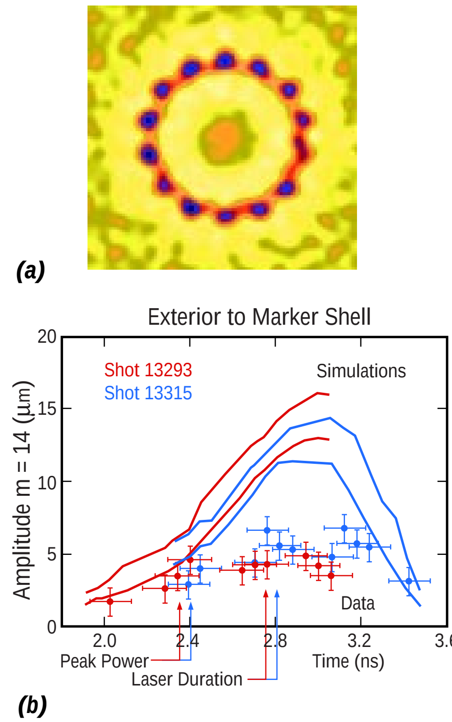


Fig. 8 (a) Post-processed simulation of an x-ray radiograph generated from a hydrodynamic calculation, including the effects of finite photon statistics. (b) Comparison of simulated and experimental measurements of mode and amplitude for an m = 14, 0.5-μm initial amplitude perturbation. The amplitude is measured at the interface exterior in radius to the chlorinated marker shell. There is disagreement in the predicted and actual mode growth late in the acceleration history.

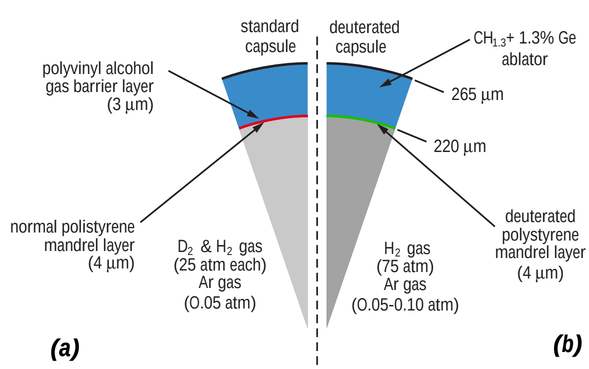


Fig. 9 Pie diagram of the standard deuterium-filled capsule (a) and the hydrogen-filled deuterated-shell capsule (b). In (a) the neutron yield is produced in the compressed deuterium gas region, while in (b) it is produced in the deuterated inner layer of the pusher heated by thermal conduction from the nonreacting gas. Higher linear growth factors are produced in capsule (b), approaching the values calculated for NIF capsules.

importance cannot be separated through a neutron yield measurement. However, we realized that in capsules made with a deuterated inner layer and filled with nonreacting hydrogen gas (Fig. 9b), increased heat loss and atomic mix would both *increase* the temperature of the deuterated layer. These deuterated shell capsule implosions would be sensitive to the interface between the pusher and the gas, but relatively insensitive to the compressed gas region. As a result, deuterated shell implosions would provide an additional and qualitatively different constraint on simulations that would be complementary to the deuterium-filled, high-growth capsule implosions and would help to determine the relative importance of the effects of perturbation growth. A series of implosions using deuterated shell capsules was performed. As described below, these implosions reached linear growth factors of ~325, approaching those predicted for NIF capsules.

The capsules were imploded by indirect x-ray drive on the Nova[15] laser using a shaped, 2.2-ns-long laser pulse with 31 kJ of energy. The capsules were mounted in 2.40-mm-long, 1.65-mm-diameter pentagonal hohlraums. The laser pulse produced a peak radiation temperature of 232 eV in the hohlraum. As shown in Fig. 9b, the capsule shells included a germanium dopant to reduce preheat of the pusher and the gas by gold *M*-band x-rays from laser-plasma interactions at the hohlraum wall, steepen the density gradient at the ablation front, and reduce the ablation rate.[16] These effects increased the perturbation growth from hydrodynamic instabilities to values approaching those calculated for NIF capsules.

To study the effect of perturbation growth on capsule performance, we varied the surface roughness of the shells by laser ablation pitting.[17] The roughness was varied by adjusting the laser energy to control the depth of the pits, and the surface perturbations were measured by atomic force microscopy.[17] The power spectrum of the surface perturbations (Fig. 10) can be used as a starting point for hydrodynamic stability calculations. The most dangerous modes are

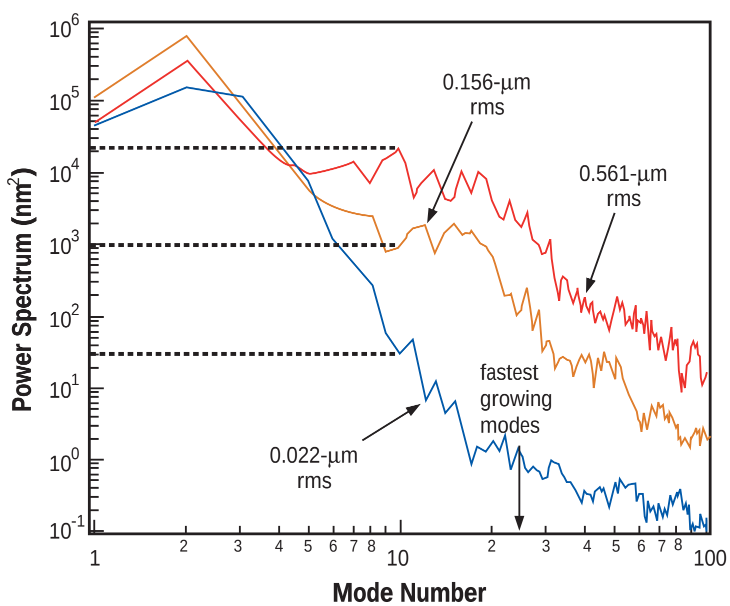


Fig. 10 ***One-dimensional power spectra for smooth and laser-roughened capsules, which can be used as a starting point for hydrodynamic stability calculations. Mode numbers below 10 have much slower predicted growth rates and are excluded from calculations by substituting the power in mode 10, as indicated by the dashed lines.***

expected to be those with wavelengths similar to the capsule thickness. As a simple measure of the surface roughness, the power spectrum is also summed to obtain the surface variance and, from the square root of the variance, the root-mean-square (rms) surface roughness. Low mode numbers (below 10) have much slower calculated growth rates than modes in the range 10–30 and are excluded from the surface variance summation by substituting the power in mode 10 for the power in modes 1–9.

The observed dependence of yield on surface roughness is shown in Fig. 11. The neutron yields are obtained from Nova's Tion[18] and LaNSA[19] single-interaction neutron detector arrays located at 27 m and 20 m, respectively, from the target. The neutron yields are approximately constant for surface roughness up to 0.2 µm and decrease for rougher surfaces. X-ray images (in the 3–4 keV photon energy range) of 1-µm-roughness capsules at peak compression are distinctly larger and weaker than the images at other surface roughnesses (Fig. 12), suggesting that these shells have broken up

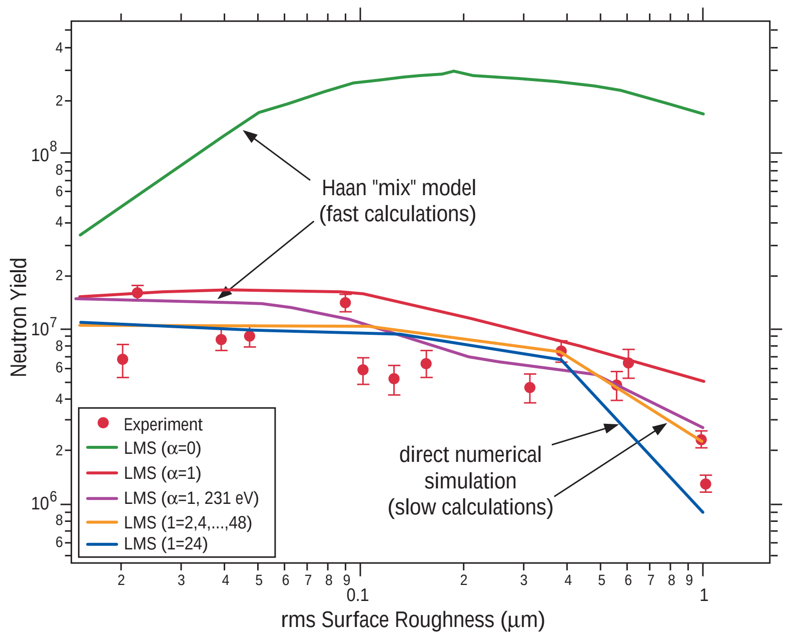


***Fig. 11** Variation of measured and simulated (LMS and DNS) neutron yield with surface roughness. All experimental data points are from the Tion array except two points at 1-µm rms roughness from the LaNSA array. This table illustrates that the simulations fit well with the results except in the case of the LMS α = 0 simulation.*

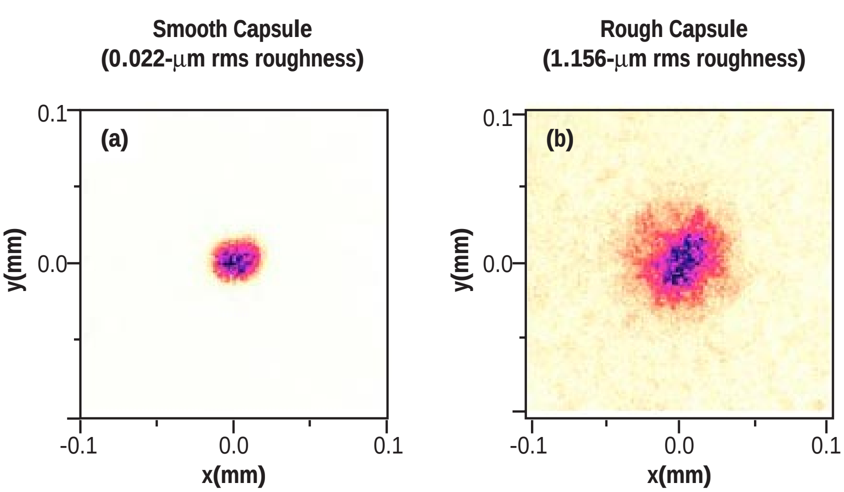


***Fig. 12** Gated x-ray images of smooth and rough capsules at peak compression times. In general, capsules with roughnesses ≥1 µm produced larger, weaker images, suggesting that the capsules broke up during the implosion.*

during the implosion. The image diameters at the 50% intensity contour for the smooth and 1-μm-roughness capsules are 25 ± 5 μm and 50 ± 10 μm, respectively. The neutron energy spectrum, summed over all the shots, had a full-width-at-half-maximum (FWHM) energy spread of 99 ± 6 keV. This energy spread, if caused solely by thermal motion of the deuterons[20], would correspond to an ion temperature T_i = 1.43 ± 0.17 keV. However, the neutrons could also be subject to Doppler broadening from bulk fluid motion[21] during the time of neutron production as a result of the motion of the deuterated layer.

We performed two types of simulations of these implosions. The first type is known as direct numerical simulation (DNS).[22,23] It involves direct calculation of perturbation growth using the LASNEX[24] 2-D radiation hydrodynamics code, starting with a realistic mode spectrum and following the perturbations into the nonlinear regime. Neutron yield and other observables are calculated at the same time as the perturbation growth. The simulation involves no adjustable parameters associated with hydrodynamic instabilities, heat conductivity, or mode saturation. The simulations directly predict the nonlinear "bubble and spike" structures on the inner surface of the capsule which increase the inner surface area and thus heat loss from the gas. Furthermore, DNS explicitly predicts the reduction in compressional heating of the gas as a result of perturbation growth. For small rms roughness, the yield predictions of DNS are nearly independent of roughness and are the same whether they are started with a spectrum of 24 modes (ℓ = 2, 4,. . ., 48) or with the same roughness in the dominant mode (ℓ = 24). However, for large rms roughness (>0.4 μm), when the shell is beginning to break up, the single-mode ℓ = 24 calculations predict a more rapid decrease in yield than the multimode calculations, as expected for the dominant mode.

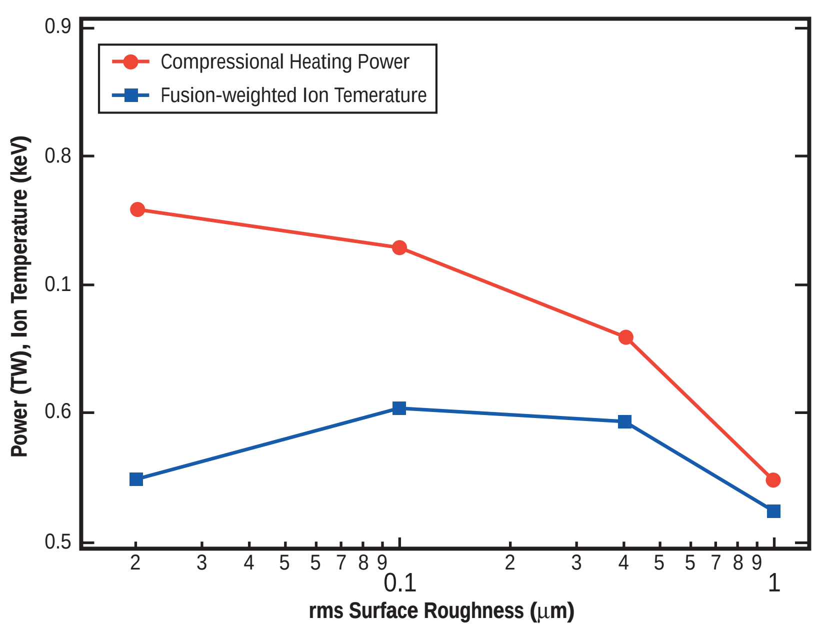


***Fig. 13** Variation of DNS calculations of peak compressional heating power (circles) and peak fusion-weighted ion temperature (squares) with capsule surface roughness.*

DNS predictions are in quantitative agreement with the measured yields (Fig. 11), and thus provide a confirmation of the method. Both single- and multi-mode DNS yields decrease slowly with surface roughness up to 0.4-μm and then begin to fall more rapidly. The most obvious effect of perturbation growth in DNS is a reduction in the peak compressional heating power. The decrease in compressional heating is partially compensated for by an increase in the temperature of the deuterium. This effect is manifested in DNS as an increase in the fusion-reaction-weighted ion temperature (Fig. 13). The increase in temperature from a smooth implosion to 0.1-μm roughness corresponds to a nearly two-fold increase in fusion reactivity, and is roughly balanced by a similar decrease in the average density of the deuterated layer. These simulations indicate fully developed turbulence and shell breakup for implosions with roughness greater than 0.4 μm, in agreement with the experiments.

DNS predictions for the x-ray image sizes are similar to the experimental observations. The diameter of the x-ray images in the 3–4 keV range at the time of peak emission is predicted to be 29 μm for smooth capsules, increasing to 33 μm for 0.4-μm-roughness and 43 μm for 1-μm-roughness capsules. The maximum intensity of the images is also predicted to decrease by a factor of two from the smooth to the roughest capsules, similar to the trend toward weaker images in the experiments.

The ion temperature inferred from the neutron spectra (1.4 keV) is higher than the DNS predictions and corresponds to a 200-times larger fusion reactivity. To reconcile the measured yields with this temperature, one would have to postulate a 200-fold reduction in the product of deuterium density, inventory, and burn duration. Any such explanation would be difficult to reconcile with simulations of other ICF implosions, which typically match the average measured yield within 30%. On the other hand, mass flows can increase the neutron energy spread without increasing the fusion reactivity. Neutron spectra calculated by post-processing the output of DNS calculations show the qualitative effect of broadening by mass flow, especially in the early part of the burn when spike speeds are largest. Quantitatively, however, the calculated mass-flow broadening integrated over the entire burn duration is insufficient to explain the observed spectral width. This discrepancy may indicate that significant mass-flow broadening occurs at scales too small to be resolved in the calculations, that the symmetry enforced in 2-D single-hemisphere calculations causes unrealistic stagnation of the flow, or that 3-D spikes in the experiment travel faster than 2-D spikes in the calculations. Neutron energy broadening from mass flow may also be important in other ICF experiments whenever deviations from spherical symmetry produce flows in the gas region with speeds approaching 1×10^7 cm/s during the fusion burn.

The second type of simulation, known as linear mode superposition and saturation (LMS), has been extensively applied to NIF capsule design.[25] It begins with a calculation using LASNEX of the linear growth rates of individual spherical harmonic modes (with infinitesimal amplitudes) seeded at the outer surface. The calculated linear growth factors (ratios of final and initial mode amplitudes without any mode saturation) are largest for modes between 20 and 24, and reach ~325 at the time of peak neutron emission. The individual modes are superimposed, using the measured initial surface perturbations on the capsule and including a saturation criterion for the growth rate of each mode.[26] The procedure is used to predict the rms amplitude L of the perturbations at the gas-pusher interface throughout the implosion. An annulus of width L is assumed to be mixed on an atomic scale. Once the extent of the mixed region is known, the neutron yield is predicted in a separate one-dimensional (1-D) calculation. Since LMS simulations do not account for increased surface area in the mixed region, an enhancement to the usual electron thermal conductivity is applied in that region, with a diffusion coefficient having a form given by $\alpha L\dot{L}$ where α is an adjustable multiplier.

The LMS predictions of neutron yield are shown in Fig. 11 for two values of α. For comparison, the yield predicted in a clean 1-D simulation is 9.9×10^6. A large increase with increasing surface roughness, followed by a decrease, is predicted for the yield as the surface roughness increases when enhanced heat loss is not included ($\alpha = 0$). The yield is predicted to increase because the shell converges farther as gas effectively leaks into the shell via mix. Further mixing reduces the central temperature and hence the neutron yield. The prediction using $\alpha = 0$ is clearly inconsistent with the measurements. When enhanced heat loss is included ($\alpha = 1$), the predicted yield varies by less than a factor of three with surface roughness because the effects of mix and heat loss nearly balance each other. Calculations with larger values of α (up to 5) differ little from the $\alpha = 1$ predictions. The variation with roughness shows that the yield is insensitive to the extent of the mix region which, at the time of peak neutron emission, varies between 4-μm spike growth for smooth capsules and 19-μm spike growth for capsules with initial 0.5-μm rms roughness. This lack of sensitivity arises because, as deuterated shell material moves closer to the hotter capsule center due to increasing perturbation growth, it also conducts heat away more quickly, so the temperature in the mix region stays approximately constant. The yield measurements cannot, therefore, be used to distinguish between different ways of modeling nonlinear hydrodynamic perturbation growth (DNS *vs*. LMS). The results do, however, demonstrate the importance of including enhanced heat loss in LMS modeling and also illustrate the relative importance of competing effects in determining the physical conditions in the burn region. The yield is most sensitive to the temperature in the shell which is, as these results show, insensitive to perturbation growth. However, the temperature in the shell is very sensitive to the radiation drive, as illustrated by an LMS calculation with a peak drive temperature of 231 eV (Fig. 11). For peak drive temperatures of 231–233 eV, consistent with the experimental drive, the yields predicted by LMS are very close to those predicted by DNS and also in good agreement with the data (Fig. 11).

In conclusion, we have performed the first measurements and numerical simulations of fusion yield from the gas-pusher interface of

ICF implosions. The yields predicted by DNS are found to be in quantitative agreement with the measured yields, even in the highly nonlinear regime where shell breakup occurs, without using adjustable parameters for enhanced thermal losses or mix. These measurements also show that, in a mix model based on LMS and saturation, enhanced heat loss in the mixed region is essential to match the yields. The neutron energy spectrum shows enhanced broadening, most likely arising from bulk fluid motion of the deuterated layer. The sensitivity of these measurements to the gas-pusher interface helps to test capsule implosion simulations in a way that is not possible with conventional implosions, and thereby helps to validate the models used to design ignition capsules for the NIF laser.

References

[1] J. D. Lindl, “Development of the Indirect-Drive Approach to Inertial Confinement Fusion and the Target Physics Basis for Ignition and Gain,” *Physics of Plasmas* 2, 3933 (1995).

[2] W. W. Hsing, C. W. Barnes, J. B. Beck, N. Hoffman, D. Galmiche, A. Richard, J. Edwards, P. Graham, S. Rothman, and B. Thomas, “Rayleigh-Taylor Instability Evolution in Ablatively Driven Cylindrical Implosions,” *Physics of Plasmas* 4, 1832 (1997).

[3] W. W. Hsing and N. M. Hoffman, “Measurement of Feedthrough and Instability Growth in Radiation-Driven Cylindrical Implosions,” *Physical Review Letters* 78, 876 (1997).

[4] P. L. Gobby, L. J. Salzer, R. D. Day, J. J. Bartos, Jr., G. Rivera, D. J. Hatch, F. P. Garcia, R. Manzanares, L. R. Foreman, and H. Bush, Jr., “Micromachining of Inertial Confinement Fusion Targets,” *Nuclear Instruments and Methods for Physics Research A* 397 (1997) 183.

[5] G. I. Bell, “Taylor Instability on Cylinders and Spheres in the Small Amplitude Approximation,” Los Alamos National Laboratory Technical Report LA-1321, Los Alamos Scientific Laboratory (1951).

[6] M. S. Plesset, “On the Stability of Fluid Flows with Spherical Symmetry,” *Journal of Applied Physics* 25, 96 (1954).

[7] S. W. Haan, “Weakly Nonlinear Hydrodynamic Instabilities in Inertial Fusion,” *Physics of Fluids B* 3, 2349 (1991).

[8] Cris W. Barnes, D. L. Tubbs, J. B . Beck, N. M. Hoffman, K. A. Klare, J. A. Oertel, R. G. Watt, T. R. Boehly, D. K. Bradley, and J. P. Knauer, “Experimental Configuration of Direct Drive Cylindrical Implosions on the OMEGA Laser,” *Review of Scientific Instruments* 70, 476 (1999).

[9] D. L. Tubbs, C. W. Barnes, J. B. Beck, N. M. Hoffman, J. A. Oertel, R. G. Watt, T. Boehly, D. Bradley, and J. Knauer, "Direct Drive Cylindrical Implosion Experiments: Simulations and Data," *Lasers and Particle Beams* (to be published in 1999).

[10] Sarah A. Voss, C. W. Barnes, J. A. Oertel, R. G. Watt, T. R. Boehly, D. K. Bradley, J. P. Knauer, and G. Pien, "Gated X-Ray Framing Camera Image of a Direct-Drive Cylindrical Implosion," *IEEE Transactions on Plasma Science Triannual Issue on Images in Plasma Science* (to be published in 1999).

[11] D. P. Smitherman, R. E. Chrien, N. M . Hoffman, and G. R. Magelssen, "The Feed-out Process: Rayleigh-Taylor and Richtmyer-Meshkov Instabilities in Uniform, Radiation-Driven Foils," *Physics of Plasmas* 6, 932 (1999); D. Palmer Smitherman, R. E. Chrien, N. M. Hoffman, and G. R. Magelssen, "Feed-out Coupling of Richtmyer-Meshkov and Rayleigh-Taylor Instabilities in Stratified, Radiation-Driven Foils," *Physics of Plasmas* 6, 940 (1999).

[12] D. L. Tubbs, C. W. Barnes, J. B. Beck, N. M. Hoffman, J. A. Oertel, R. G. Watt, T. Boehly, D. Bradley, P. Jaanimagi, and J. Knauer, "Cylindrical Implosion Experiments using Laser Direct Drive," *Physics of Plasmas* 5 (to be published in 1999).

[13] C. J. Keane, G. W. Pollak, R. C. Cook, T. R. Dittrich, B. A. Hammel, O. L. Landen, S. H. Langer, W. K. Levedahl, D. H. Munro, H. A. Scott, and G. B. Zimmerman, "X-ray Spectroscopic Diagnostics of Mix in High Growth Factor Spherical Implosions," *Journal of Quantitative Spectroscopy and Radiative Transfer* 54, 207 (1995).

[14] O. L. Landen, C. J. Keane, B. A. Hammel, W. K. Levedahl, P. A. Amendt, J. D. Colvin, M. D. Cable, R. Cook, T. R. Dittrich, S. W. Haan, S. P. Hatchett, R. G. Hay, R. A. Lerche, R. McEachern, T. J. Murphy, M. B. Nelson, L. Suter, and R. J. Wallace, "Effects of Variable X-Ray Preheat Shielding in Indirectly Driven Implosions," *Physics of Plasmas* 3, 2094 (1996).

[15]E. M. Campbell, "Recent Results from the Nova Program at LLNL," *Lasers and Particle Beams* 9, 209 (1991).

[16] S. V. Weber, B. A. Remington, S. W. Haan, B. G. Wilson, and J. K. Nash, "Modeling of Nova Indirect Drive Rayleigh-Taylor Experiments," *Physics of Plasmas* 1, 3652 (1994); B. A. Remington, S. V. Weber, S. W. Haan, J. D. Kilkenny, S. G. Glendinning, R. J. Wallace, W. H. Goldstein, B. G. Wilson, and J. K. Nash, "Laser-Driven Hydrodynamic Instability Experiments," *Physics of Fluids B* 5, 2589 (1993).

[17] R. J. Wallace, R. L. McEachern, and W. W. Wilcox, "Laser Ablation Machining of ICF Capsules," *ICF Quarterly Report* 4, 79–86,

Lawrence Livermore National Laboratory report UCRL-LR-105821-94-3 (To obtain a copy of this document, request Document No. DE 95011970 from the National Technical Information Service, Springfield, VA 22161).

[18] R. E. Chrien, D. F. Simmons, and D. L. Holmberg, "Neutron Time-Of-Flight Ion Temperature Diagnostic for Inertial-Confinement-Fusion Experiments," *Review of Scientific Instruments* 63, 4886 (1992).

[19] M. B. Nelson and M. D. Cable, "LaNSA: A Large Neutron Scintillator Array for Neutron Spectroscopy at Nova," *Review of Scientific Instruments* 63, 4874 (1992).

[20] H. Brysk, "Fusion Neutron Energies and Spectra," *Plasma Physics* 15, 611 (1973).

[21] T. J. Murphy, R. E. Chrien, and K. A. Klare, "Neutron Time-of-Flight Signals from Expanding or Contracting Spherical Sources," *Review of Scientific Instruments* 68, 614 (1997).

[22] N. M. Hoffman, D. C. Wilson, W. S. Varnum, W. J. Krauser, and B. H. Wilde, "Multimode Hydrodynamic Stability Calculations for National Ignition Facility Capsules," 12th International Conference on Laser Interactions and Related Plasma Phenomena (Osaka, Japan, April 1995), *Laser Interations and Related Plasma Phenomena*, S. Nakai and G. H. Miley, Eds. (American Institute of Physics Press, Woodbury, New York, 1996).

[23] W. J. Krauser, N. M. Hoffman, D. C. Wilson, B. H. Wilde, W. S. Varnum, D. B. Harris, F. J. Swenson, P. A. Bradley, S. W. Haan, S. M. Pollaine, A. S. Wan, J. C. Moreno, and P. A. Amendt, "Ignition Target Design and Robustness Studies for the National Ignition Facility," *Physics* of *Plasmas* 3, 2084 (1996).

[24] G. Zimmerman and W. Kruer, "Numerical Simulation of Laser-Initiated Fusion," *Comments on Plasma Physics and Controlled Fusion* 11, 51 (1975).

[25] S. W. Haan, S. M. Pollaine, J. D. Lindl, L. J. Suter, R. L. Berger, L. V. Powers, W. E. Alley, P. A. Amendt, J. A. Futterman, W. K. Levedahl, M. D. Rosen, D. P. Rowley, R. A. Sacks, A. I. Shestakov, G. L. Strobel, M. Tabak, S. V. Weber, G. B. Zimmerman, W. J. Krauser, D. C. Wilson, S. V. Coggelshall, D. B. Harris, N. M. Hoffman, and B. H. Wilde, "Design and Modeling of Ignition Targets for the National Ignition Facility," *Physics of Plasmas* 2, 2480 (1995).

[26] S. W. Haan, "Onset of Nonlinear Saturation for Rayleigh-Taylor Growth in the Presence of a Full Spectrum of Modes," *Physical Review A* 39, 5812 (1989).

Trident Research Campaigns

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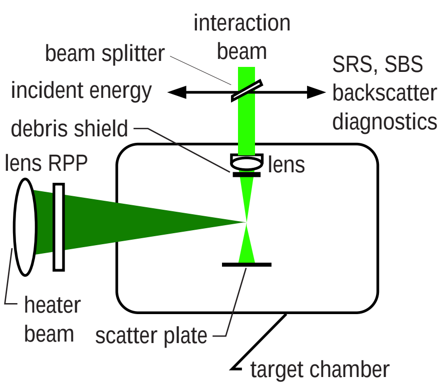

Fig. 1 Schematic top-view of the laser beam and diagnostic configurations used in the single hot-spot interaction experiments.

Introduction

During the past two years, the Trident laser facility has provided over 2,200 laser shots for 25 different experimental campaigns involving experimentalists from Los Alamos National Laboratory, Sandia National Laboratory, Lawrence Livermore National Laboratory, and colleges and universities around the country and the world, including Imperial College and Oxford University in the United Kingdom, Ecole Polytechnique in France, the University of Maryland, the University of Michigan, and the University of California at San Diego. Roughly one-quarter of the Trident experimental campaigns have been fielded by personnel from the Los Alamos Plasma Physics Group (P-24) for diagnostic development or testing of diagnostics in preparation for experiments at Trident or Livermore's Nova or the University of Rochester's Omega laser systems. The remaining experimental campaigns have been independent experimental campaigns fielded to address the individual goals of various universities or to support the goals of the local Inertial Confinement Fusion (ICF) Program. Most of the laser time was devoted to two major experimental programs, one to study laser plasma instabilities and the other to study dynamic properties of materials. University users were also involved as collaborators in these two very important areas.

Most campaigns were carried out on the main Trident target chamber, but a number of campaigns were accomplished on two auxiliary target chambers using Trident's short-pulse capability. Some of these involved diagnostic development, testing, and calibration while others addressed the nature of the interaction of a very high-intensity laser pulse with a plasma. These latter campaigns were conducted to test aspects of the fast-ignitor concept for ICF ignition at the National Ignition Facility (NIF).

This research highlight will focus on the two experimental campaigns that used most of the laser time. The first is sponsored by the Laboratory Directed Research and Development (LDRD) Program to study laser plasma instabilities. Its focus is to study the interaction of a single laser hot spot with a pre-formed plasma with a view to understanding, in more realistic laser beams, the parametric scattering instabilities that pose a threat to ICF ignition. The second campaign, part of the dynamic properties of materials program, focussed on developing experimental techniques to study shock-induced melt and other phase transformations in materials under the extreme conditions of interest to ICF and weapons physics. These campaigns are discussed individually below.

Characterizing Plasma and Laser Conditions for Single Hot-Spot Interaction Experiments

Laser beams are scattered by density fluctuations (waves) in a plasma because these fluctuations alter the index of refraction that the laser encounters. With low amplitude waves, this process (called collective Thomson scattering) is benign, and it provides a powerful tool for diagnosing plasma conditions. On the other hand, stimulated scattering involves the unstable growth of waves in the plasma fed by the laser energy. These waves can scatter a significant fraction of the laser energy in undesirable directions. Stimulated scattering by electron plasma waves (Raman scattering) and ion-acoustic waves (Brillouin scattering) poses a significant threat to ICF.

The Trident laser system was used for fundamental experiments addressing the interaction of laser self-focusing, stimulated Raman scattering (SRS), and stimulated Brillouin scattering (SBS) in a near-diffraction-limited (single) laser hot spot under ICF-relevant plasma conditions. Our aim was to gain a better understanding of the coupling between these plasma instabilities. This laser-plasma system is sufficiently small for direct modeling by an emerging suite of computer codes incorporating new theoretical models. If we succeed in understanding this system, we hope to develop simpler models suitable for quantitative predictions in much larger ignition plasmas. The first step in this process is to create an ignition-relevant plasma and to characterize it thoroughly and accurately.

In our investigation, one of Trident's three 527-nm laser beams was used to create and heat a long-scale-length plasma (~1 mm, ~0.6 keV). A second, lower-energy Trident beam was then used to produce a nearly diffraction-limited interaction laser beam with minimal wave-front distortion incident in the target plasma. Figure 1 shows a schematic of the laser and diagnostic configuration used in our experiments.

The plasma heater beam was focused with an *f*/6 aspheric lens and a "stripline" random phase plate (RPP), which produces a line focus with dimensions of ~100-μm high × 1,000-μm long.[1] The laser energy is 160 ± 10 J in a 1.3-ns pulse at constant power with 100-ps rise and fall times. It illuminates a 1-mm-diameter plastic or aluminum target at normal (perpendicular) incidence with the line focus in the horizontal plane. The interaction beam was focussed on the target using an air-spaced achromat lens with a 250-mm focal length (*f*) positioned at *f*/7. This lens was mounted inside the vacuum chamber where the plasma is generated, so a high-quality debris shield was placed between the lens and target to protect the lens. The interaction beam was incident 90° to the heater beam and was offset parallel to the target surface by between 100 and 400 μm to vary the sampled plasma density. The 200-ps interaction beam was delayed by 1.8 ± 0.05 ns with respect to the beginning of the heater beam so that the heater beam was off when the interaction pulse was on. This delay is important because it removes any influence of the heater beam on the experiment.

A beam splitter was placed in the interaction beam to sample the incident beam energy and the reflected light from the plasma scattering processes. The extensive diagnostics for the scattered light on Trident, used to study SRS and SBS, are beyond the scope of this article and will not be described.

To characterize the interaction laser, we measured the focal plane intensity distribution using a 40× microscope objective and a charge-coupled device (CCD) camera. Figure 2 shows an image of the interaction laser at best focus (a) and an azimuthally averaged

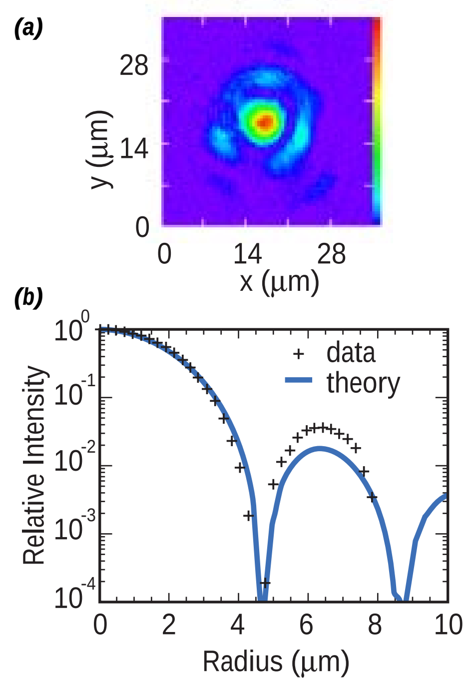

***Fig. 2** (a) Far-field image of the single hot spot beam (the colors represent light intensity with red being the highest, blue being the lowest, and black being no intensity). (b) Azimuthally averaged radial profile of the far field data, with diffraction from an ideal f/7 beam superimposed.*

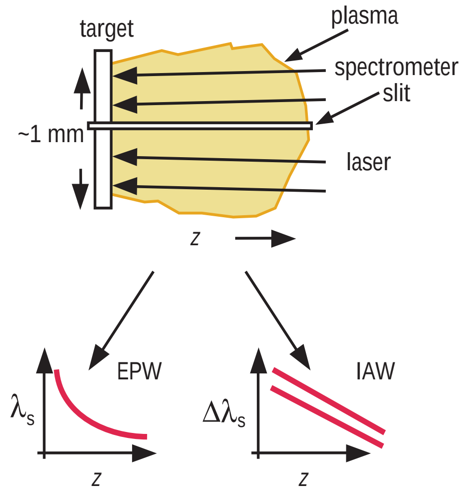

***Fig. 3** Schematic bottom-view of the target and the imaging spectrometer orientation with respect to the target and heater beam for Thomson scattering measurements. The graphs show a cartoon of the expected scattering from EPWs and IAWs for this configuration.*

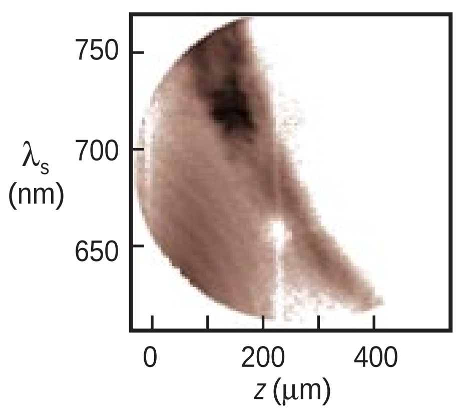

***Fig. 4** Scattering from EPWs as a function of distance from the target surface at t = 1.0 ± 0.1 ns for a plastic plasma. The vertical features at z = 0 and z = 200 µm are artifacts due to dead spots on the detector.*

radial profile (b). Superposed is the theoretical radial profile for diffraction from a plane wave incident on a circular aperture at $f/7$ (the theoretical ideal performance), which is in excellent agreement with the measured results.

The interaction laser beam has a full-width at half maximum (FWHM) of 3.8 ± 0.15 µm, and it produces a peak intensity of 1×10^{16} W/cm^2 for a nominal energy of 0.8 J (maximum) in a 200-ps FWHM Gaussian pulse. The peak intensity can be adjusted between 10^{14} and 10^{16} W/cm^2 using polished, calibrated neutral density filters.

We measured the angular distribution of the transmitted interaction laser by having the transmitted beam illuminate a diffuser, which was then imaged onto a CCD camera filtered for 527 ± 5 nm. The camera system was absolutely calibrated so that transmitted energy measurements were obtained. This measurement, which is important to diagnose the laser-plasma instabilities, will not be discussed further.

To characterize the plasma, we used a 5-cm focal length, $f/6$ achromat to collect Thomson scattered light at 90° from the heater beam. The target was imaged onto the slit of a 0.5-m imaging spectrometer with the image oriented along the direction of the plasma expansion, perpendicular to the target surface. The output of the spectrometer was coupled to a gated optical camera with ~120-ps frame time and the image was recorded using a CCD camera. The spectrometer was operated in either low or high dispersion to measure Thomson-scattered signals from electron plasma waves (EPWs) or ion acoustic waves (IAWs).

A schematic of the Thomson scattering measurement is given in Fig. 3, which also shows the slit orientation with respect to the target image. The sampled scattering volume at the target plane was ~10 µm wide (slit width) with ~100-µm line-of-sight depth through the plasma. The imaging direction of the spectrometer is oriented along the plasma-expansion direction, allowing reconstruction of the scattered-light profile with a 25-µm resolution.

Scattering from EPWs was examined to obtain measurements of the plasma density profile. Using the dispersion relations for the EPWs and scattered light, the scattered light should go from long wavelength near the target surface to shorter wavelength farther away as the density goes from high to low, as indicated in the graph in Fig. 3. Figure 4 shows a corresponding measurement of scattering from EPWs versus distance from the target near the end of the heater pulse (t = 1.0 ± 0.1 ns) for a 6.5-µm-thick plastic target. The spectrum at a given distance from the target surface shows a cutoff at a maximum wavelength, which corresponds to the peak density at that position. A density profile is obtained from the data by finding the edge of the maximum wavelength cutoff versus position, and assuming an electron temperature, T_e, equal to 0.5 ± 0.1 keV in the dispersion relations. A plot of the inferred electron density, n_e/n_{cr}, where n_{cr} is the critical density ($n_{cr} = 4 \times 10^{21}$ cm^{-3}, above which 527-nm light does not propagate), *vs.* position from the target surface is shown in Fig. 5.

Collective Thomson scattering from IAWs is used to measure profiles of electron temperature (T_e), ion temperature (T_i), and flow velocity (v_z). The scattering geometry determines the wave-number of the IAWs being probed and is given by $k_{IAW} = 2k_0 \sin(\Theta/2)$, where $k_0 = 2\pi/\lambda_0$ is the laser wave-number, and Θ is the angle between the incident and scattered light. The dispersion relations indicate that the separation between the upshifted and downshifted IAWs is a function of T_e, and the flow velocity produces a Doppler shift of the entire spectrum, as indicated in the graph in Fig. 3 for an isothermal plasma, which turns out to be a good assumption. A corresponding measurement of Thomson-scattered light from IAWs *vs.* distance is shown in Fig. 6 near the end of the heater pulse ($t = 1.0 \pm 0.1$ ns) for a 6.5-µm thick plastic target. The separation between the upshifted and downshifted waves is clearly resolved, and the entire spectrum becomes more Doppler shifted further from the target surface, indicating an increased flow speed at increased separation from the target surface.

A spectral lineout taken at the location $z = 300 \pm 25$ µm is shown in Fig. 7. The spectrum is asymmetric, indicating a relative drift between electrons and ions, and is due either to transport effects or

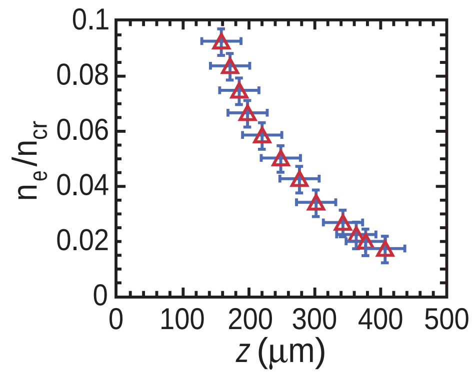

***Fig. 5** The electron density profile* vs. *distance from the target surface obtained from the EPW data shown in Fig. 4.*

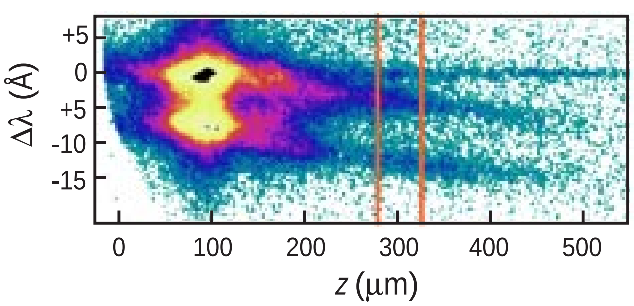

***Fig. 6** Scattering from IAWs as a function of distance from the target surface at $t = 1.0 \pm 0.1$ ns for a plastic plasma.*

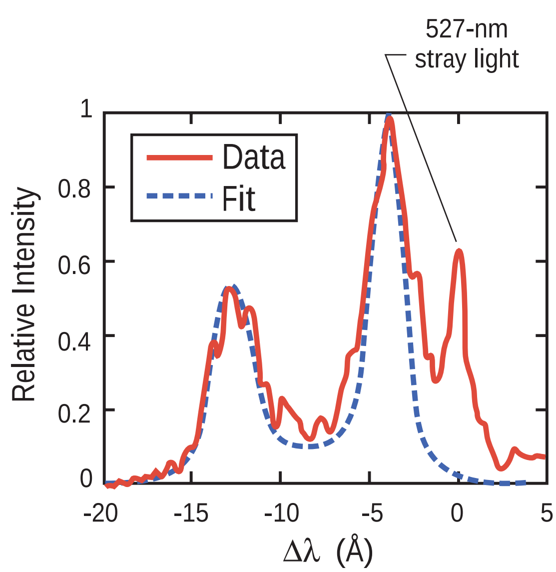

***Fig. 7** Spectral profile taken from the IAW data shown in Fig. 6 at $z = 300 \pm 25$ µm. Superimposed is a fit for the Thomson scattering form factor for a fully ionized plastic plasma, with fit parameters $T_e = 0.7 \pm 0.1$ keV, $T_i = 0.14 \pm 0.05$ keV, and $v_z = 4.8 \pm 0.4 \times 10^7$ cm/s. The spectral line at $\Delta\lambda = 0$ is due to stray 527-nm light, which provides a convenient wavelength fiducial.*

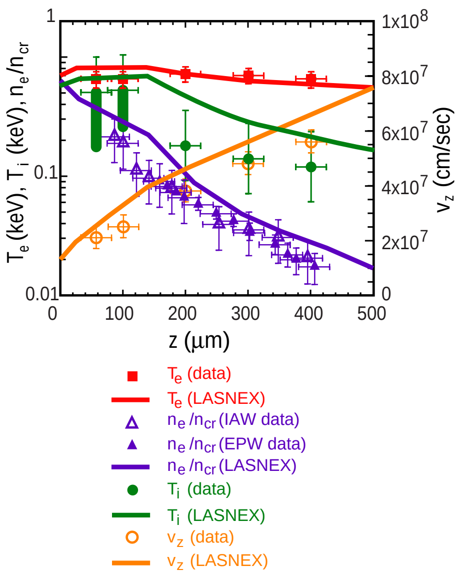

***Fig. 8** Plot of electron density (n_e/n_{cr}), electron temperature (T_e), ion temperature (T_i), and flow velocity (v_z) profiles at $t = 1.0 \pm 0.1$ ns measured by Thomson scattering from the EPW and IAW data shown in Figs. 4 and 6. Simulated plasma profiles from 2-D LASNEX calculations are also shown.*

to stimulated processes. The separation between peaks is mostly dependent on electron temperature, T_e, and weakly dependent on ion temperature, T_i. The width of each peak and the contrast between the center of the spectrum and the peak heights are dependent on T_i, and the overall Doppler shift from λ_0 depends on flow velocity. The entire spectrum is fitted using the Thomson scattering form factor for multi-ion species plasmas[2], and is used to determine T_e, T_i at that position. The flow velocity, v_z, is determined assuming that the dominant flow component is mostly parallel to the heater beam. Figure 8 shows the experimentally measured profiles of n_e/n_{cr}, T_e, T_i, and v_z at $t = 1.0 \pm 0.1$ ns for a plastic target derived from the Thomson scatter data shown in Figs. 4 and 6. Calculations of the plasma profiles using the 2-D hydrodynamics code LASNEX[3] are also shown as lines in Fig. 8 and are in rough agreement with the measurements. These data can be used to further refine the simulations for the experimental design.

In summary, we have produced ignition-relevant long-scale plasmas on Trident. The plasma conditions have been characterized with unprecedented detail using Thomson scattering. A nearly diffraction-limited laser beam suitable for interaction experiments has been produced and thoroughly characterized. Given these measurements, theoretical simulations of laser-plasma instability processes will be performed, and detailed comparisons to measurements will be made. We expect to gain sufficient understanding of these processes to allow the development of models suitable for quantitative predictions on ignition-scale plasmas.

Shock Wave Physics and High Pressure Materials Science Research

P-24, in collaboration with Los Alamos National Laboratory's Materials Science and Technology (MST), Dynamic Experimentation (DX), Applied Theoretical and Computational Physics (X), and Theoretical (T) Divisions, as well as Oxford University, Livermore, Sandia, the University of California at San Diego, and the University of Edinburgh, pursues an active research program in shock-wave physics and related materials science. The Trident laser system is used to drive moderate to high-pressure shock waves into condensed-state materials, and the response of the materials is diagnosed with an array of advanced diagnostics. These measurements are used to determine dynamic properties of materials that are of importance to the inertial fusion and the weapons programs. A modest-size laser system like Trident is well suited to certain areas of high-pressure materials science, providing accurate and flexible control over the temporal profile of shock generation, a wide range of achievable pressures (~0.05–30 Mbar), and very bright x-ray sources accurately synchronized to the shock generation. In addition, many shots can be fielded rapidly for accurate studies of various parameters. This section gives a brief review of some of the recent high-pressure materials work on the Trident laser.

A typical configuration for Trident materials science experiments is shown in Fig. 9. In this particular case the principal diagnostic method was transient x-ray diffraction[4], a method to which Trident experiments have made significant contributions. One beam of the laser system is used to drive a shock wave into the sample. Another beam is used to generate an intense x-ray source, in this case a point source of 6.1-keV radiation. In this example the x-rays diffract off planes roughly parallel to the entrance surface. This mode of diffraction is referred to as Bragg diffraction. As the shock wave reaches the rear surface of the crystal, the lattice planes are compressed and the Bragg angle of diffraction is changed. The angular deflection of the diffracted x-ray beam is thus directly proportional (through Bragg's law) to the real time-strain induced in the crystal by the shock wave. An example of typical data obtained using such a configuration is given in Fig. 10.

The x-ray streak record shown in Fig. 10 illustrates several important aspects of the shock propagation and its effect on the diffraction of x-rays. The lower portion of the streak represents diffraction from unshocked material before the shock wave has reached the rear surface of the crystal. As the shock comes within the probe distance of the x-rays, a portion of the diffracted x-rays are deflected to a higher angle and thus strike the streak camera slit at a different position. The separation of this streak from the uncompressed portion is directly proportional through Bragg's law to the strain induced in the crystal by the shock wave. The strains induced are typically large, on the order of a few percent. The strain rates are also quite large, ranging from 10^7 to 10^9 s^{-1}. The dynamics of solid-solid phase changes is one important phenomenon that can be studied by such methods.

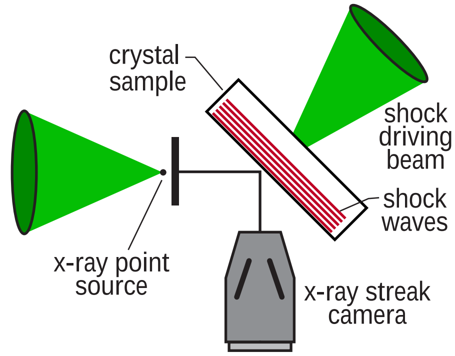

Fig. 9 A typical experimental configuration used on the Trident laser for shock wave and materials science studies.

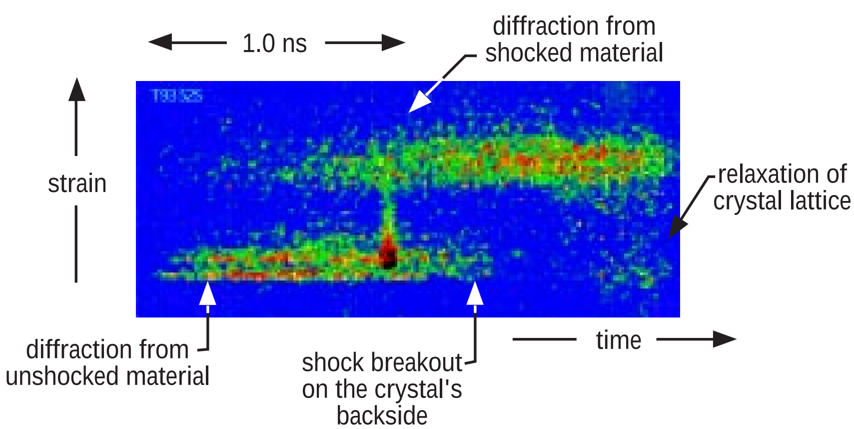

Fig. 10 Typical example of transient diffraction data obtained in shock wave materials research on the Trident laser. The peak shock pressure was about 150 kbar.

Figure 11 illustrates typical data from phase change studies. The several shots displayed represent a progression of increasingly higher shock pressure (generated by higher laser irradiances). In this case the diffraction is occurring from the <400> planes of a silicon crystal. At a particular threshold in pressure, the crystal goes through a phase change from the normal diamond cubic configuration to another configuration, most likely a body-centered tetragonal configuration. In the highest-pressure streak, the diffraction from compressed material is seen to split into two components indicative of the phase change. Through records of this sort, the dynamic properties of the phase change can be studied. These data are currently being compared with hydrodynamic simulations that include a new multiphase equation of state. This equation of state takes into account the observed phase change. Recent simulations using this multiphase equation of state have predicted that the dynamic threshold for this phase change should occur at about 200 kbar, which is quite close to the threshold that is observed experimentally. The next stage of this research will extend this work to another phase change: melt.

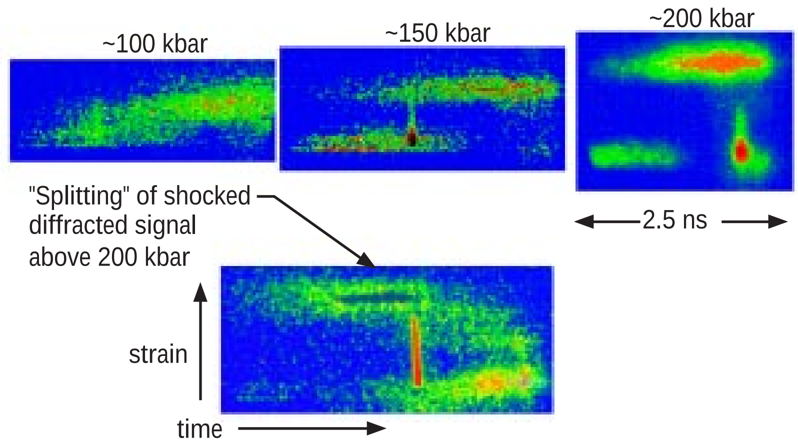

***Fig. 11** Transient diffraction data from a material undergoing a shock-induced phase change.*

Other materials science work on Trident focuses on plastic wave generation. Plastic behavior of materials occurs when shock waves have pressures above the elastic limit. Typically, condensed matter subjected to pressures above the elastic limit yields through generation of dislocations and other faults in the crystalline structure. One method for diagnosis and analysis of these fault generation mechanisms is post-shot analysis of the materials. Special systems “catch” the fragments of material after the shock event. Thin slices of the material are then subjected to analyses such as transmission electron microscopy. An example of this analysis is given in Fig. 12. The characteristic dislocation signatures indicate where the material has yielded when subjected to the high-pressure shock wave. The next stage of this research will compare the dislocation generation with molecular dynamics modeling. Molecular dynamics modeling is the most basic, first-principles approach to predicting the response of condensed materials to high-pressure shock waves. (The comparisons will be made with molecular dynamics calculations performed by Brad Holian and his colleagues in T-11 and T-12.) It represents a first step in building a comprehensive picture of material behavior beginning at the atomic level and progressing to dislocation generation and finally macroscopic faults. The data obtained in experiments such as these can help to critique and benchmark this modeling.

Experiments on the Trident laser system have provided useful data on the dynamic properties of materials. In particular, we have developed new transient x-ray diffraction methods for studying the temporal structure of shock-induced solid phase changes, and methods for post-shot analysis of shock-induced dislocation generation. In addition, experimental data on phase changes have been compared with hydrodynamic modeling that uses the most advanced multiphase equations of state. The thresholds for the phase change predicted by the modeling agree well with experimentally observed values.

Trident experiments have also provided a useful test bed for developing new measurement methods and techniques that can be applied to larger-scale materials work on pulsed-power machines, gas guns, and explosive facilities. This review represents only a short summary of the broad range of materials research that we conduct using high-power radiation sources and pulsed-power radiation generators. We believe that this research will provide a useful supplement to traditional methods relying on explosives to generate the high pressures.

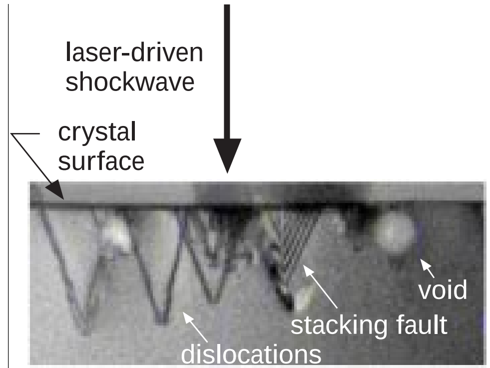

***Fig. 12** Electron microscopy analysis of dislocations generated by a high-pressure laser-driven shock wave.*

References

[1]B. S. Bauer, R. P. Drake, K. G. Estabrook, J. F. Camacho, R. G. Watt, M. D. Wilke, G. E. Busch, S. E. Caldwell, and S. A. Baker, “Meeting the Challenge of Detecting Ion-Plasma Waves,” *Physics of Plasmas* 2, 2207 (1995).

[2]D. E. Evans, "The Effect of Impurities on the Spectrum of Laser Light Scattered by a Plasma," *Plasma Physics* 12, 537 (1970).

[3]G. Zimmerman and W. Kruer, "Numberical Simulation of Laser-Initiated Fusion," *Comments on Plasma Physics and Controlled Fusion* 2, 51 (1975).

[4] A. A. Hauer and G. A. Kyrala, “Laser-Plasma X-Ray Emission: Its Creation, Diagnosis and Application in Transient Diffraction,” in *Time Resolved Diffraction*, J. R. Helliwell and P. M. Rentzepis, Eds. (Oxford Clarendon Press, Oxford, 1997), pp. 71–103.

Development of an Infrared Imaging Bolometer

G. A. Wurden and H. A. Alvestad (P-24)

Introduction

As magnetic fusion plasmas become larger, hotter, and therefore contain more energy, precise control of the plasma becomes even more critical. Today's fusion plasmas are generally "shaped" to allow for more efficient confinement of the plasma by magnetic fields. Shaping requires the plasma position to be both measured and controlled on timescales ranging from milliseconds to hours. This control requires a range of diagnostic tools that measure as many plasma parameters as possible. These plasma diagnostics must be able to survive for long periods in a harsh environment consisting of nuclear radiation (gamma rays and neutrons), vacuum conditions, exposure to plasma bombardment, and strong magnetic fields. In developing such diagnostics, the necessary access requirements, sensitivity, noise, and cost per channel (of a multichannel instrument) must also be considered. To meet these needs, we have developed and patented an imaging bolometer system (U.S. Patent 5,861,625) using infrared readout of a segmented metal foil. Our bolometer allows hundreds to thousands of channels of data, it requires no wiring harness, and it is intrinsically radiation-hard.

Infrared Imaging Bolometer

A bolometer is an instrument that measures the total radiation incident upon it, preferably with an appropriate time resolution. Bolometers are used to study the radiation emission profiles of fusion plasmas, which provide valuable information about the locations and amounts of plasma impurities. Often, the radiation emitted by a fusion-grade plasma is "hollow," that is, it is localized in the outer regions of the plasma. The magnitude of the radiation emitted by the plasma will usually be in the range of 10–100% of the heating power (from 10 kW up to tens of Megawatts), which sustains the plasma. Most bolometers use a material, such as gold, platinum, or tantalum, to absorb the radiation and convert it into heat. The resulting temperature increase is detected by monitoring some physical characteristic of the material. This characteristic could be the change in resistance, a piezo-electric effect, or (in our case) the amount of infrared radiation emitted by the absorbing material. In all present-day, large-scale plasma devices, large arrays of single-element bolometers have been used to measure the plasma's radiation profile. The systems are hampered by the fact that each detector requires at least two wires carrying low-level signals through the vacuum vessel to the outside world. The wiring is difficult to install and maintain (insulators degrade in radiation fields), and it is a source of background noise.

Bolometers are not a new diagnostic. Our work, however, offers new capabilities for plasma diagnostics by combining the latest digital state-of-the-art infrared video technologies (developed originally for missile interceptor programs and the Clementine spacecraft that flew to the moon). These infrared video cameras operate in the 3- to 12-μm wavelength band with

12-bit dynamic range, sensitivity limits of $\Delta T = 0.01°C$, arrays of 256×256 elements, and read-out rates of up to 1 kHz, and are now commercially available. We use such a camera to view a customized segmented-foil that we developed, generating a time-resolved image of the radiation emitted from a plasma.

Radiation damage on conventional bolometers, which need insulators for wiring and usually have multilayered thin film materials that might blister under intense radiation exposure, is a serious concern for the next generation of fusion experiments and reactors. Our bolometer offers an elegantly simple solution. It uses no wires and no insulators, it uses only metal components near the plasma, and it relies on the bulk property (thermal heat capacity) of a metal. These characteristics make this instrument very robust, relatively radiation-resistant, and more stable over the long term. Given these characteristics, it is possible that our instrument might be used on an International Thermonuclear Experimental Reactor (ITER) class (1 GW level) fusion reactor for long periods of time before requiring replacement.

In years past, infrared readout of the back side of a single, thin-foil "detector" has been used to measure the radiation power incident on the front side of the foil. Such detectors were typically used to eliminate particularly difficult electromagnetic interference problems that arise due to pick-up in the leads of traditional resistive readout bolometers. Similarly, infrared cameras have been used to take "snapshots" of the distribution of heat on a foil exposed to a pulsed ion or neutral beam. Such snapshots can be used to diagnose the beam profile, but they do not provide any time resolution. The initial heat distribution is "frozen in" on the foil for a few video frames. To measure a subsequent beam pulse, the researcher had to wait until the heat either diffused or radiated away and then "reinitialize" the foil to avoid confusion. This technology has many limitations. For example, to simultaneously use hundreds or thousands of detectors (bolometer "pixels"), the researcher must have a way to keep the heat deposited on one pixel from flowing into the adjacent pixel, or risk confusing the measurements. In addition, if the expected temperature rise on the foil is around 10°C per second, as it would be in long-pulse plasma applications, then the foil material would melt without active cooling.

Our goal was to develop a multi-element imaging bolometer that is actively cooled, but with thermally isolated pixels. Our first idea was to use a "back-cooled, front-viewed" configuration. The concept was tested with a bed of roofing nails, as shown in Fig. 1. Each nail (pixel) is thermally isolated from its neighbor and cooled by an "infinite heat sink" in which the nail is anchored. In this design, the decay time of the heat on the nails was much too long for plasma applications, but it provides a good graphical illustration of the concept of a segmented sensor matrix.

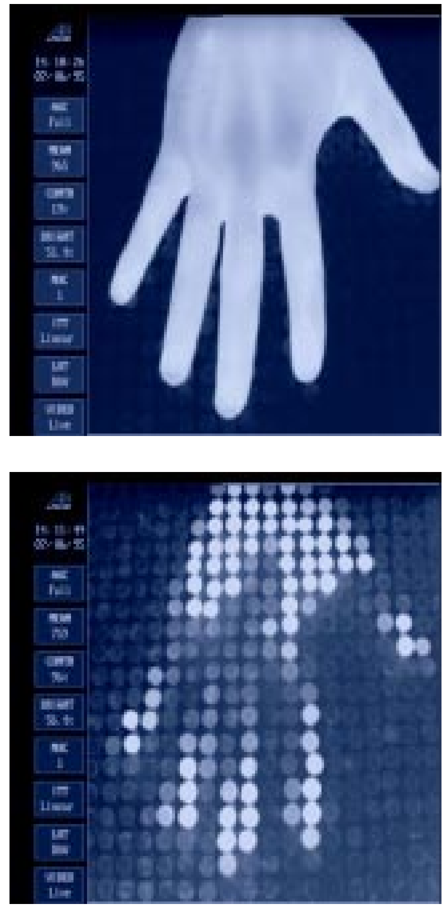

***Fig. 1** An array of 20 × 20 roofing nails was used to test the concept of a "back-cooled, front-viewed" bolometer configuration. The heads of the nails are thermally isolated from each other, as shown in these two infrared pictures. The top image is a hand, and the bottom image is the thermal image of the hand remaining on the heads of the nails.*

Subsequently, we changed to a “back-viewed, side-cooled” design, recognizing that stray thermal radiation from hot armor tiles in the plasma vacuum vessel might contaminate the measurement. This modified design is shown in an artist’s conception in Fig. 2. To maximize the sensitivity (minimize the heat capacity), the foil must be as thin as is mechanically possible; however, to ensure that the desired range of plasma radiation (up to ~1–10 keV photons) is absorbed in the foil, the foil must be thick enough to stop soft x-ray photons.

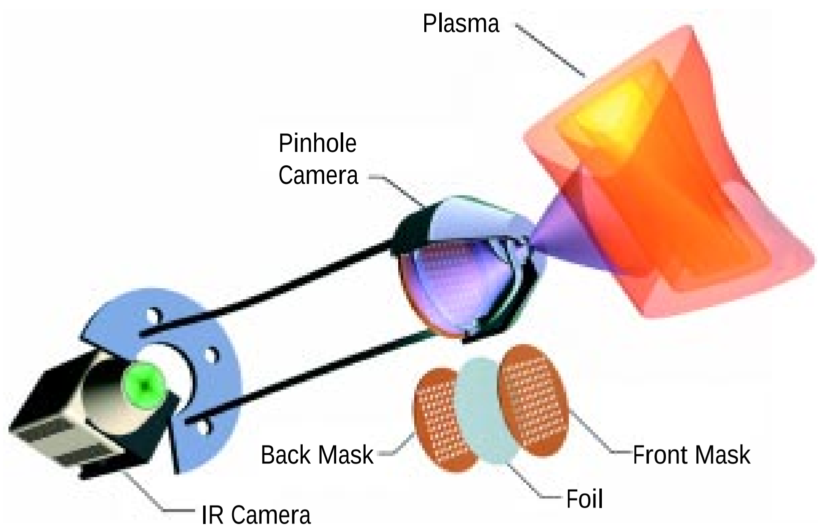

***Fig. 2** Artist’s sketch of the infrared imaging bolometer, which employs a pinhole camera design with a mask/foil combination viewed by a digital infrared video camera.*

International Collaboration

In the absence of a Los Alamos-based, large-scale fusion plasma research facility, Los Alamos scientists pursue international collaborations to field new diagnostic tools. In the Plasma Physics Group (P-24), we are involved in ongoing collaborations with researchers at the Japanese Atomic Energy Research Institute (JAERI) using the JT-60U machine, which is the world’s largest operating tokamak. We are also collaborating with researchers at the National Institute for Fusion Science (NIFS) in Toki, Japan, where the Large Helical Device (LHD), a $1B-class superconducting stellarator, will soon be in operation (see Fig. 3). As part of the U.S. Department of Energy Japan Fusion Exchange Agreement, we began collaborating with NIFS scientists to develop a plasma diagnostic that would meet the needs of the future LHD.

The LHD plasma will have a complex, helical shape. To understand the behavior of this plasma, multiple sight-lines and preferably even multiple imaging diagnostics will be required. In addition, because the LHD is a superconducting machine, long pulse operations will be used. These pulse operations might range from 10 minutes to one hour, limited only by heating in the sources and the available electric power grid. Such long-pulse operation will require a diagnostic that is able to gather enormous quantities of data with real-time data-handling capabilities.

In the summer of 1997, we performed the first plasma tests on a prototype diagnostic system using the Compact Helical Stellarator (CHS) plasma at Nagoya University. Using an Amber Radiance 1 digital infrared camera (3- to 5-μm band) with 25-millidegree sensitivity and both 0.5- and 1.0-μm thick gold foils, we obtained signals from a short-pulse (~100-ms duration) plasma heated by electron cyclotron and neutral beam sources. We blackened the backside of the gold foils with a carbon spray to obtain a thermal emissivity of nearly 1, which means that each foil's infrared emission represents its temperature. In addition to the expected signals, we found unwanted heating from stray microwave radiation used to create and heat the plasma. Typically, 10 mW of energy produces a signal of 4°C on the foil.

We performed a second series of tests in spring of 1998 using an Agema Thermovision camera (8- to 12-μm band) with a fast linescan (2.5 kHz) mode of operation, which allowed better time resolution, more in accordance with the short duration

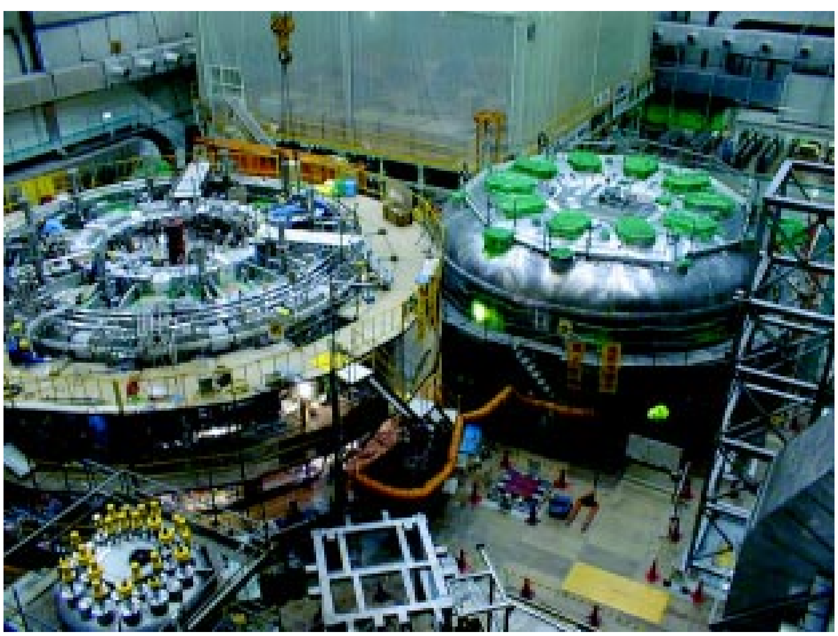

***Fig. 3** The superconducting LHD device under construction in October 1997 at the NIFS site in Toki, Japan. The stainless steel cyrostat is visible on the right, while the stellarator is largely hidden by scaffolding on the left.*

(~100 ms) test plasma. These tests fully qualified the instrument and our models, and will allow us to proceed with the real diagnostic on the LHD plasma.

Upcoming Work

In the coming year, we hope to install a second-generation prototype of our imaging bolometer on a shared port with a tangential view in the superconducting, long-pulse LHD. This will give us a view of the full plasma cross section, and it should allow us to obtain time-resolved images of the total plasma radiation similar to the visible light image in Fig. 4 (but with less spatial resolution). Based on the tests to date, our imaging bolometer already shows great promise in becoming a key diagnostic for the LHD, the world's largest superconducting experimental fusion device. We anticipate that the success of this collaboration will lead us to apply our diagnostic and pulsed-power skills to other major fusion experiments around the country and the world.

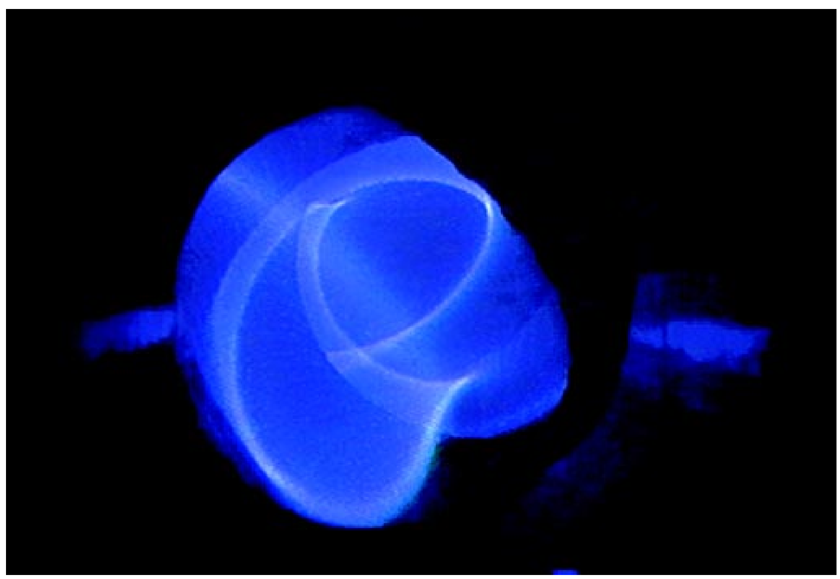

***Fig. 4** The complex shape of today's plasmas, as seen in this visible light tangential view of the LHD stellarator in Toki, Japan, requires diagnostics with imaging capabilities.*

Further Reading

G. A. Wurden, “ A Rad-Hard, Steady-State, Digital Imaging Bolometer System for ITER,” in *Diagnostics for Experimental Thermonuclear Fusion Reactors*, P. E. Stott, *et. al.*, Eds. (Plenum Press, New York, 1996), pp. 603–606.

G. A. Wurden and B. J. Peterson, “Imaging Bolometer Development for Large Fusion Devices,” ITER Diagnostics Workshop (Varenna, Italy, September 1997), in *Diagnostics for Experimental Thermonuclear Fusion Reactors*, P. E. Stott, *et. al.*, Eds. (Plenum Press, New York, 1998), pp. 399–408.

G. A. Wurden, B. J. Peterson, and S. Sudo, “Design of an Imaging Bolometer System for the Large Helical Device,” *Review of Scientific Instruments* 68, 766 (1997).

Proton Radiography

J. B. McClelland for the Proton Radiography Team: Physics Division (PDO); Neutron Science and Technology (P-23); Subatomic Physics (P-25); Nuclear and Hydrodynamic Applications (XNH); Computational Science Methods (X-CM); Code Integration (X-CI); Detonation Science and Technology (DX-1); Hydrodynamic Applications (DX-3); Field Operations and Experiment Support (DX-4); Experiment and Diagnostic Design (DX-5); Machine Science Technology (DX-6); Accelerator Physics and Engineering (LANSCE-1); Accelerator Maintenance and Development (LANSCE-2); Neutron and Nuclear Science (LANSCE-3); Accelerator Operations and Technical Support (LANSCE-6); High Intensity Beam Lines, Accelerator Experimental Areas, and Remote Handling (LANSCE-7); Nuclear Theory and Applications (T-2); Weapon Engineering (ESA-WE); Lawrence Livermore National Laboratory; Bechtel Nevada; and the Indiana University Cyclotron Facility

Introduction

Los Alamos National Laboratory is leading a multilaboratory effort to demonstrate protons as a viable new radiographic probe to image imploding or exploding objects with high spatial and temporal resolution. Proton radiography represents a sharp departure from flash x-ray radiography techniques, which have been used to image dynamic processes for over 40 years. In the past, protons were used for imaging only thin objects, but the technique was limited because the proton's charge caused multiple scattering of the proton in the object, leading to a blurred image. However, we have recently demonstrated a magnetic lens system that removes the majority of the blur—even for thick objects. This technique can be extended to gain information on the material composition of an object in addition to its density by cascading two lenses with different angular apertures—a feature that conventional x-ray radiography cannot match.

An advanced radiographic capability is an essential component of the Laboratory's Science-Based Stockpile Stewardship (SBSS) program because it provides the ability to measure the integral performance of stockpiled primaries using inert materials and thereby derive nuclear performance information that previously could be obtained only from nuclear testing. Detailed data from hydrodynamic experiments are the necessary starting points for modeling the explosion phase of the primary and thus for assessing the performance and safety of stockpiled primaries.

In the interest of expanding our hydrotest capabilities to include experimental validation of calculated nuclear performance, the Advanced Hydrotest Facility (AHF) has been proposed (Fig. 1). The AHF will provide improved understanding of three-dimensional (3-D) effects associated with aging and weapons features, as well as time-dependent, high-resolution measurements of pit density and gas-cavity configurations. The AHF will require an advanced radiographic capability that provides accurate information about densities and material positions, from which we can infer the degree of supercriticality, the shape of the boost cavity, and the mix that would be present in an actual imploding primary. Allowed manufacturing tolerances can cause an implosion to be 3-D (deviating from two-dimensional symmetry) even in normal operation, and accidental detonations are almost always 3-D. As a result, radiographs are needed from a number of directions (at least four and preferably 12) so that material densities can be reconstructed with accuracies sufficient to derive nuclear parameters. Also, since the implosion progresses with time, a temporal series of radiographs (5–10) is needed over a time period relevant to the processes being recorded. This time window may need to cover a period as long as the full implosion.

Currently, two radiography options are being considered for the AHF, one using multi-GeV protons and one using multi-MeV x-rays. Ultimately, the results for both options will be compared to determine an optimal technology mix for the AHF. Because an actual hydrotest at 50 GeV was not feasible at existing high-energy accelerator facilities, the Tri-Laboratory External Advisory Committee for Advanced Hydrotesting Research, which oversees AHF development, deemed that a combination of dynamic experiments at the Los Alamos Neutron Science Center (LANSCE) using 800-MeV protons and a suitable static demonstration at 25 GeV at Brookhaven National Laboratory's Alternating-Gradient Synchrotron (AGS) would provide enough data to evaluate proton radiography as a viable candidate for the AHF.

In collaboration with scientists, engineers, and technicians from Lawrence Livermore National Laboratory, Lawrence Berkeley National Laboratory, Brookhaven National Laboratory, Indiana University, and Bechtel Nevada, we have been collecting the data necessary to make that assessment. This research highlight provides an overview of proton radiography and a summary of the work that has been (or will be) done at LANSCE and the AGS.

Overview of Proton Radiography

Hydrodynamic radiography refers to a technology used to view inside thick material objects (specifically the primaries of nuclear weapon assemblies) as they are undergoing implosion and compression because of the detonation of surrounding high

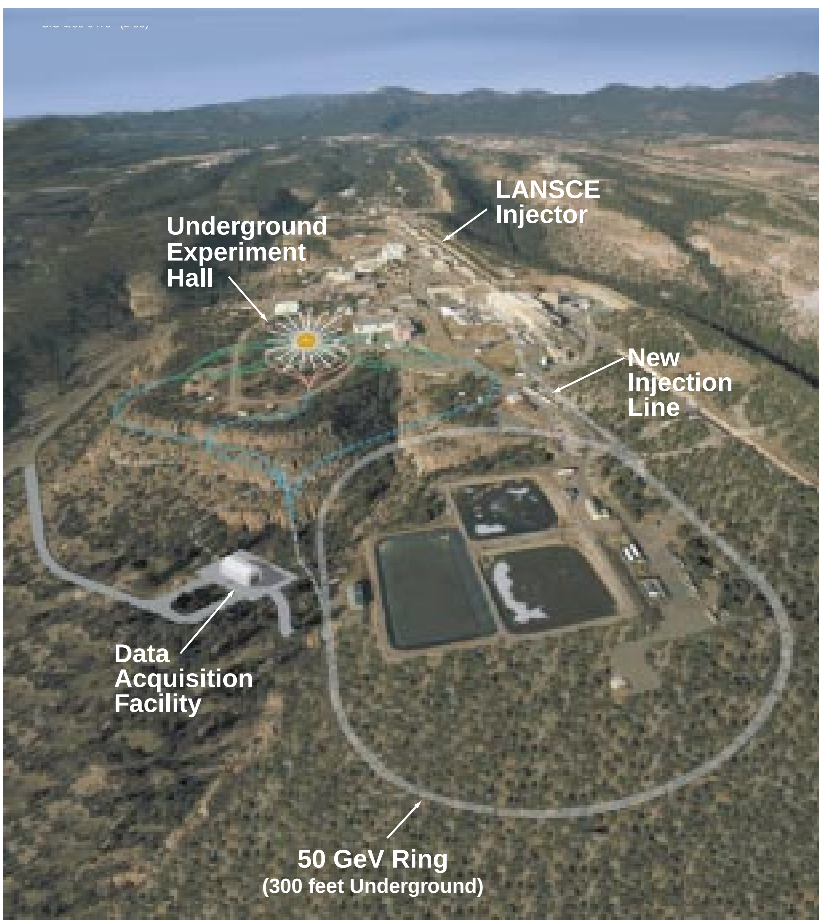

***Fig. 1** Artist's concept of the proposed 12-axis AHF.*

explosives. The principal tool of hydrotesting is thick-object-penetrating radiography. The images obtained must be formed very quickly (in ~50 ns or less) to freeze the motion of the moving components and features and to avoid motion blur. The images are negatives, in that the information depicting the primary assembly's internal structure is obtained from the attenuation of the penetrating radiation.

Such radiographs were traditionally created using x-rays, but recent experiments have demonstrated that proton radiography is a more robust solution. In proton radiography, a high-energy beam of protons impinges directly on the object to be radiographed. Unlike x-rays, protons undergo a large number of very forward-angle scatterings as they pass through the object and the exit window of the containment vessel. This introduces a blur to the image that is then removed, for the most part, by a magnetic lens system between the object and the detectors. The residual blurring can be further reduced by increasing the energy of the proton beam. For typical weapon-primary assemblies and containment-window thicknesses, submillimeter resolutions can be obtained with proton beam energies near 50 GeV, which can be produced in conventional accelerator architectures.

Protons have a number of advantages over x-rays in producing radiographic images. Protons have long, mean-free paths that are well matched for imaging thick, dense objects, and the proton results are sensitive to both material density and composition. The final images produced with protons also have a significantly higher

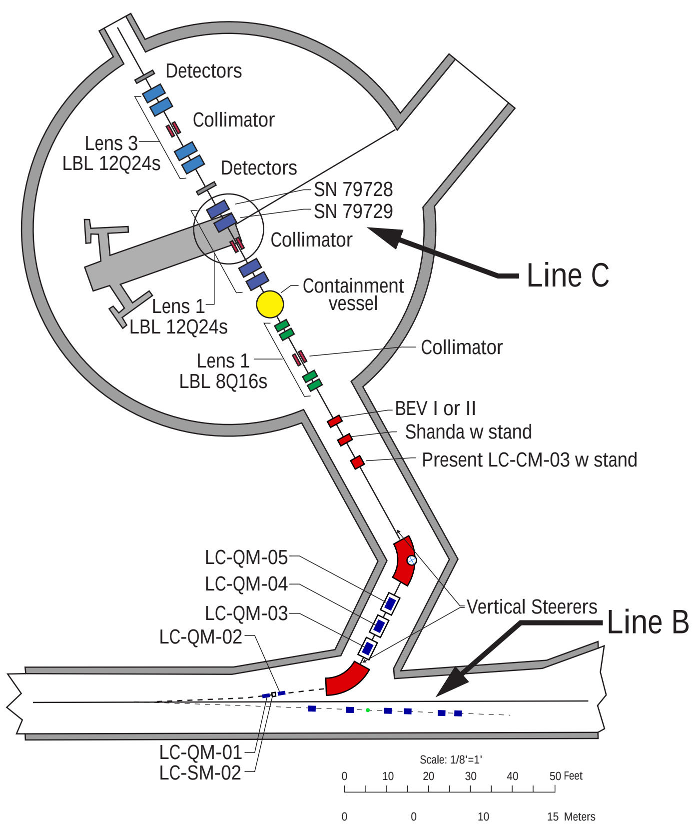

Fig. 2 Proton radiographic facilities on Lines B and C at LANSCE.

signal-to-noise ratio than x-ray images. In addition, protons provide a high detection efficiency that can generate many frames and simultaneous view directions of the explosion, producing a kind of “motion picture.” Proton radiography is also easier to execute. There is no need for a bremsstrahlung converter (which is needed to produce x-rays by converting high-intensity electron beams) because the proton beam directly illuminates the object. Furthermore, proton accelerator technology already exists to provide the required beam energies, intensities, and time structures, making this technique a viable alternative for immediate application.

Proton Radiography at LANSCE

Our experiments at LANSCE addressed specific problems involving detonation-wave propagation inside a high-explosive assembly as a function of temperature and other high-explosive properties. LANSCE is capable of providing 800-MeV protons, which are well-suited for examining shock-wave propagation in small-scale, high-explosive systems. This lower energy limits the sample candidates to relatively thin, low-Z systems. These limitations arise primarily from multiple scattering and energy loss within the object and aberrations in the lens system—effects that become less important as the beam energy increases.

In preparation for our experiments, we installed new beam line diagnostics, a containment vessel, and a lens system in LANSCE’s Line B area. Figure 2 shows a schematic of the Line B area used for the FY97 shots. Figure 2 also shows a schematic of a facility upgrade recently commissioned in Line C. The new Line C facility has a three-lens system, permitting beam, density, and material identification measurements. It is also capable of handling larger explosive charges because it can accommodate a larger containment vessel.

We conducted 25 dynamic shots on Line B from April to August 1997 to investigate the characteristics of shock propagation in different lots of high explosives over a range of temperatures. Typically, four to six frames were taken of each explosion. Figure 3 shows a detonation wave at four different times in a high-explosive assembly. The detonation wave is clearly evident in the radiographs as it propagates from the detonator to the outer surface of the explosive materials. The images were recorded on a phosphor image plate that allows one image per shot. An active camera system has now been installed and used to capture up to 12 frames in the time of a single high-explosive detonation. Future detector development is expected to provide the ability to take thousands of frames during the explosion to produce a more detailed motion picture of the event.

Many modern nuclear weapons incorporate insensitive high explosives (IHEs) to greatly reduce the chance of an accidental detonation during transportation or handling. Because of the reduced sensitivity of the IHE, its initiation and detonation is much more difficult to accurately model in computer codes, making

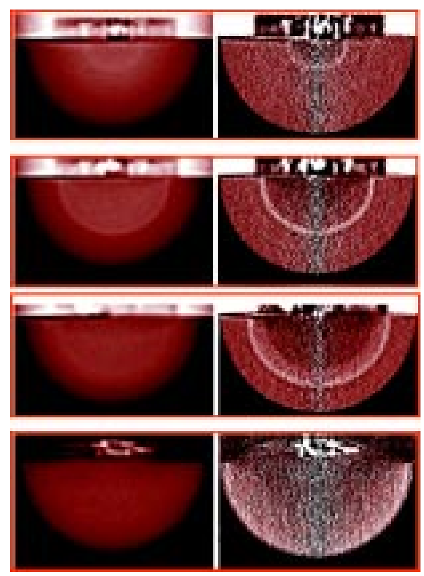

Fig. 3   Analysis results from proton radiographs of the detonation wave in a high-explosive assembly at four different times. Areal densities (left) and reconstructed volume densities (right), extracted under the assumption of axial symmetry, are shown.

reliable weapons detonation more difficult to guarantee under a wide range of conditions. The LANSCE proton radiographs provided an extensive set of data for IHE detonation for various initial conditions and temperatures. Such data show that our present calculational models have shortcomings and will help us develop and validate better models. This better understanding will help us maintain our confidence in these weapons into the future.

The dynamic experimental program at LANSCE has been an unqualified success, demonstrating our ability to perform dynamic experiments at high resolution, incorporate a containment system, eliminate blur with magnetic lenses, extract material composition using multiple lens techniques, and utilize the multiple pulse capability of the accelerator with a multiframing detection system. Upcoming experiments will include extensions of the IHE studies and high-explosives experiments in collaboration with the Atomic Weapons Establishment, Livermore, and Sandia National Laboratory.

High-Energy Proton Radiography at the AGS

In addition to our work at LANSCE, we are preparing to conduct static demonstrations using high-energy protons (up to 25 GeV) at Brookhaven's AGS. This is a major milestone because it demonstrates performance at parameters near those proposed for the AHF.

In preparation for the 25-GeV experiments, we collected data using a secondary beam from the AGS that provided only 7–10 GeV protons at low intensity. The lower intensity prevented us from performing true flash radiography, but the resulting data were able to demonstrate the low background level at the detector, confirm calculations of system performance, and prove the utility of the magnetic lens system at high energies.

To achieve a true flash radiograph of a static object, we have begun construction of a new beam line at the AGS to deliver the full energy of the accelerator (25 GeV) at full AHF intensities (10^{11} protons per pulse). We are installing two sets of lenses to allow for determination of material composition as well. The goal of the experiment is to demonstrate a few percent density measurement on a 1-mm^2 pixel size for thick objects (several hundred grams/cm^3) in the presence of a containment system. A suite of classified and unclassified static objects will be radiographed as part of this program. In addition, we will characterize the experimental backgrounds seen by the detection system. Other information on tomographic reconstruction, detector performance, and novel lens concepts will be gathered if time permits. We expect to complete the new AGS beam line and conduct a two week run in August 1999. The need for further runs will be evaluated based on the results of the August run.

Plans for a Proton Radiography Interim-Step Machine

We are currently assessing the feasibility of building a machine dedicated to testing proton radiography that would serve as an intermediate step to the AHF. Researchers from Los Alamos and Livermore have developed a concept for constructing a one- to two-axis, high-energy (25–50 GeV) ring using existing magnets from a decommissioned accelerator at Fermi National Laboratory. This proton radiography interim-step machine (PRISM) is estimated to cost approximately 10–20% of the proposed AHF and would provide a valuable testing ground to perform contained hydrotests with protons. Although limited by a minimal number of viewing axes (upgradable in the future), it would be capable of achieving full AHF resolutions, have the ability to perform material identification through a multiple lens system, and deliver the stored pulses (~20) over a long time-window using an extraction kicker system. This would provide both a technology development capability, as well as a unique tool for providing data to the SBSS program. PRISM could be constructed at either the Nevada Test Site or at Los Alamos. Advantages of a Los Alamos siting include use of LANSCE as an injector to the main ring to reduce cost, extensive accelerator infrastructure and expertise, and the existence of a vigorous hydrotesting program. Nevada Test Site offers an existing firing site. We are currently working with Livermore to evaluate these options, and we will submit a preconceptual design report within the year. An artist's concept of PRISM is shown in Fig. 4. PRISM would be a first step toward the AHF, and would include the linac (or comparable) injector, the main 50-GeV acceleration ring, a one- to two-axis extracted beam line, a firing point, and a lens/detector system.

Fig. 4 Artist's concept of PRISM.

Looking for Antiquarks in Nuclei

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Introduction

Recent experiments carried out at Fermi National Accelerator Laboratory's 800-GeV proton synchrotron have stirred the nuclear physics community in recent years by revealing unexpected phenomena in the realm of antiquark behavior. Through these experiments, our team has taken a pioneering step into a new field that combines objectives of interest to nuclear physicists with the techniques and framework of high-energy physics.

This paper describes the work that lead to this experimental effort, and it highlights the main results from Experiment 772 (E772), which began our search for antiquarks. This experiment was the beginning of a very successful collaboration that lead the same core personnel to participate in two additional experiments. The success of this collaboration is evidenced in the impact of the data on the nuclear physics community. In 1998, this work was awarded the prestigious Tom W. Bonner Prize, which recognizes outstanding experimental research in nuclear physics.

Nuclear Physics and Quarks

We all know that the aspects of nuclear physics that touch most people's lives—bombs and nuclear reactors—were invented in the 1940s and 1950s long before anyone knew about quarks and gluons. Similarly, the nuclear physics known prior to the first quark model (1964) was sufficient to understand the mechanisms for energy generation in the sun and stars. Through the development of a combination of phenomenological models, including the Nobel-Prize winning nuclear shell model, the beautiful and varied properties of nuclei could be understood at a quantitative level—all before quarks were sparkles in the eyes of their theoretical creators, Murray Gell-Mann and George Zweig, and long before the experimental discovery of quarks in 1970.

In spite of the successes of quarkless nuclear physics, in the late 1970s and early 1980s quarks, gluons, and the underlying theory of their interactions, known as quantum chromodynamics (QCD), had become so well established in particle physics that nuclear physicists were asking, "What's in it for us?"

Nucleons Under the Microscope

The mystery of quarks is still that one doesn't "see" them one at a time. They always come in threes, or baryons, of which protons and neutrons are the best known examples, or in pairs of quarks and antiquarks, or mesons, the particles whose exchange between neutrons and protons binds them into nuclei. Collectively baryons and mesons are known as hadrons. An excellent expression of this dichotomy is found in the words of the famous Russian theorist Y. L. Dokshitzer, "Quarks and gluons are the truth, but hadrons are the reality." Figure 1 illustrates the "reality" of the proton in low and high resolution pictures.

Looking for Quarks Inside Nuclei

In the early 1980s physicists were looking for an experiment that would definitively demonstrate that nuclei were more than systems of neutrons and protons bound by meson exchange—nuclei, too, would exhibit effects explainable only in terms of the truly elementary particles, quarks. The dilemma was concisely stated in an unpublished talk at the International Nuclear Physics Conference in Florence, Italy in 1983. "They [quarks] are like the Mafia in Sicily. They may be hard to spot, but you just know that they are there somewhere."

The answer to this dilemma arrived in 1983 with the publication of the now famous European Muon Collaboration (EMC) effect[1]. The EMC used 200-GeV muon beams at the European Laboratory for Particle Physics (formerly the *Centre Européenne pour la Recherche Nucléaire*, or CERN) Super Proton Synchrotron to carry out a higher-energy version of the same experiment that had led to the Nobel-Prize winning discovery of quarks at the Stanford Linear Accelerator Center (SLAC) electron accelerator. It takes an average of 8 MeV to remove a nucleon from a nucleus, and the CERN experiment used beams some 25,000 times greater in energy. A rough analogy might be a bowling ball running headlong into a bowling pin: Surely it doesn't matter whether or not the pin has been taped to the floor! Similarly, or so the experimenters presumed, it couldn't matter whether the CERN experiment used a hydrogen (deuterium) target, where the quarks are in free nucleons, or a more convenient target such as iron, where the quarks are bound in nuclei. Fortunately, the EMC group took data for both kinds of targets. The results were surprising. When the EMC compared the data, the ratio of scattering probabilities from iron and deuterium was very significantly different from unity. It mattered whether quarks were in free nucleons or bound in nuclei! This result electrified the nuclear and high-energy physics communities. Within two years of the EMC publication there were more that 300 theoretical papers written about how the data might be understood.

Antiquarks Inside Nuclei

The problem, of course, was that there was only one EMC effect, a relatively small data set that could be reproduced theoretically by many different mechanisms. What was needed was a different experiment. Many of the theorists working in this area hit upon the Drell-Yan (DY) process as the answer. In simplest terms, the DY process is quark-antiquark annihilation—the quark and antiquark are contained in two different hadrons which collide. This annihilation results in the production of a pair of leptons with

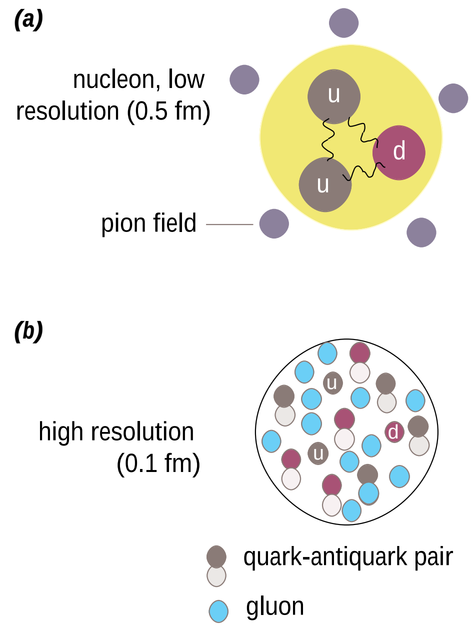

***Fig. 1** Low (a) and high (b) resolution illustrations of the proton. The basic properties of the proton, such as electric charge, are determined by two "up" quarks of charge +2/3 and one "down" quark of charge -1/3. The pion field, which provides the longest-range part of the two-nucleon interaction, consists of pairs of quarks and antiquarks. For example, the π^+ is composed of an up quark (+2/3) and an antidown quark (+1/3).*

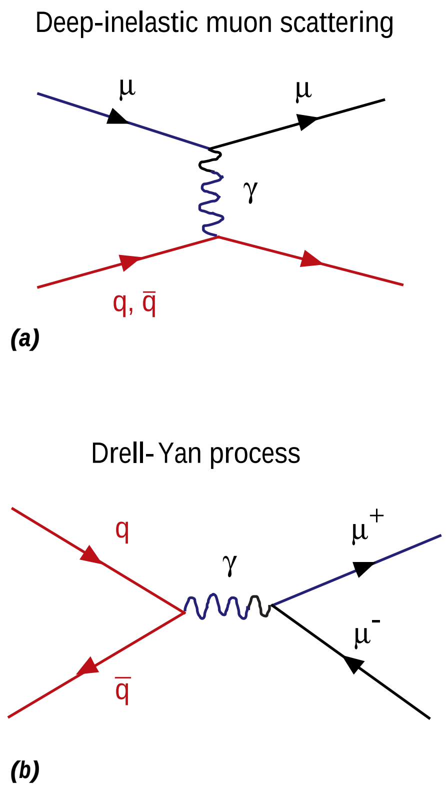

***Fig. 2** Feynman graphs for two related high-energy electromagnetic processes. In **(a)**, a high-energy muon **(top left)** collides with a quark or antiquark in the target. As the reaction proceeds to the right in time, the momentum of the muon scattered to the upper right is measured in a spectrometer. From the initial and final muon momenta, the energy transferred to the quark can be inferred. In the DY process, **(b)**, a quark from one hadron annihilates with an antiquark from a second hadron, producing a virtual photon which subsequently decays into a pair of muons. Here, by energy conservation, a measurement of the final muon momenta is sufficient to reconstruct the original colliding quark and antiquark momenta.*

very large mass. The Los Alamos Subatomic Physics Group (P-25) was introduced to this process in the early 1980s in a seminar given by theorist Gerry Miller of the University of Washington.

Figure 2 shows the relation between deeply inelastic lepton scattering (DIS), the original quark-discovery reaction, and its close cousin, the DY process. The DY process was "discovered" theoretically in 1970, near the time of the first DIS experiments at SLAC. It was verified experimentally at Fermilab and CERN in the late 1970s only after the experimental techniques were developed for measuring this process, which has a very small cross section in the presence of huge backgrounds.

Our contributions began around 1985–86. We discovered that a measurement of the nuclear dependence of the DY process at the level of precision of the EMC effect had never been made. We also discovered that the theoretical issues connected with a quantitative understanding the DY process had largely been resolved in the early 1980s. Thus, it was time for a new experiment. But not just any DY experiment would do. The experimental conditions had to be arranged for maximum sensitivity to antiquarks in the target. In brief, this required a beam of high-energy protons—not pions or antiprotons—and a spectrometer to detect the highest-energy, most forward-going dimuons. Fortunately, these conditions could be met using an existing spectrometer and beamline at Fermilab. In 1986 a bare-bones group consisting of Jen-Chieh Peng, Gerry Garvey, and Joel Moss from Los Alamos National Laboratory and Chuck Brown and Bob McCarthy from a previous Fermilab collaboration concocted a proposal, which eventually became the now famous E772. Its title was, "Study of the nuclear antiquark sea via proton-induced dimuon production." These collaborators managed to rebuild, reconfigure, and successfully operate the relic Fermilab spectrometer to accomplish the required precision measurement—a significant achievement that, from proposal to publication, took only three years.

Where are the Nuclear Pions?

The E772 collaboration made a precision comparison of DY muon-pair production on targets of deuterium, carbon, calcium, iron, and tungsten. The surprising result was that there is almost no difference in the antiquark density in the heaviest targets compared to deuterium, quite unlike what was found for quarks in the EMC experiment. From almost any conventional view of nuclei, in which nucleons are bound by the exchanges of mesons, this is an enigma. After all, in quark-model terms, mesons are quark-antiquark states. So what happens to the antiquarks in nuclei? There are many ways to quantify this dilemma. Suffice it to say here that conventional meson exchange naturally leads to excesses of antiquarks in heavy targets in the range of 5–20%. The E772 data, on the other hand, are inconsistent with more than 2–4% enhancement.

Publication of the E772 results lead to considerable theoretical hand wringing. In 1993, George Bertsch, Leonid Frankfurt, and Mark Strikman addressed the issue in an article entitled ”Where are the Nuclear Pions?” To illustrate the level of debate, a few months later the eminent nuclear theorist Gerry Brown and his collaborators published a rebuttal of sorts, entitled provocatively, “Where the Nuclear Pions Are!” Their explanation, based on a scale change associated with partial restoration of chiral symmetry, has not gained a large following. It is fair to say that much of the nuclear physics community is still mystified over the E772 data.

The Pion Field of the Proton

The newest contribution to our understanding of the E772 data has occurred only recently as a result of experiments performed in the 1990s. The most significant of these experiments was Fermilab E866, an effort lead by P-25 scientists Gerry Garvey, Pat McGaughey, and Mike Leitch in collaboration with scientists from other Los Alamos National Laboratory groups, Abilene Christian University, Argonne National Laboratory, Fermilab, Georgia State University, the Illinois Institute of Technology, Louisiana State University, New Mexico State University, Oak Ridge National Laboratory, Texas A&M, and Valparaiso University. The major results from this experiment were discussed in detail in a previous research highlight.[2]

In summary, the E866 collaboration employed the same reaction as performed eight years earlier by E772, the venerable DY process. This time, the goal was to find a telltale signature of the proton’s pion field. In simplest terms, that signature is the presence of an excess of antidown quark caused by the virtual emission of a pion in the process $p \rightarrow n + \pi^+$. The DY process easily picks out the extra antidown quark. The experiment was carried out by making a precision comparison of DY production from both proton and neutron targets. Of course neutrons are not stable, so one uses the best substitute, deuterium, which contains a neutron and a proton. The experiment made use of two 20-cm-long liquid targets containing hydrogen and deuterium, and a significantly upgraded version of the E772 spectrometer.

The result of the E866 measurement (consistent with two previous but less precise experiments) is that the excess of antidown quarks with respect to antiup quarks in the proton is very nicely accounted for by the proton’s pion field. This is an important milestone in the study of the quark structure of nucleons as it is the most compelling evidence to date of a strong link between the low resolution (meson-nucleon) and high resolution (quark) pictures of the nucleus (Fig. 1).

Where Do We Go from Here?

Since the characteristic signature of the pion field has been so clearly seen at the quark level, the lack of excess antiquarks in nuclei seems even more perplexing. Where do we go from here? The standard answer for an experimentalist is, of course, “more experiments.” In fact, an experiment is already being prepared at Thomas Jefferson National Laboratory. There, experimenters will try to detect the pions responsible for nuclear binding by knocking them out of light nuclei using 4-GeV electrons. Will the pions be there in the substantial numbers indicated by the very sophisticated nuclear models developed in recent years? The nuclear physics community will surely speculate, but only time—and experimental data—will tell.

References

[1] J. J. Aubert, G. Bassompierre, S. K. H. Beck, C. Best, E. Bohm, X. Debouard, F. W. Brasse, C. Broll, S. Brown, J. Carr, R. W. Clifft, J. H. Cobb, G. Coignet, F. Combley, G. R. Court, G. Dagostini, W. D. Dau, J. K. Davies, Y. DeClais, R. W. Dobinson, U. Dosselli, J. Drees, A. W. Edwards, M. Edwards, J. Favier, M. I. Ferrero, W. Flauger, E. Gabathuler, R. Gamet, J. Gayler, V. Gerhardt, C. Gossling, J. Haas, K. Hamacher, P. L. Hayman, M. Henckes, V. Korbel, U. Landgraf, M. Leenen, M. Maire, H. Minssieux, W. Mohr, H. E. Montgomery, K. Moser, R. P. Mount, P. R. Norton, J. McNicholas, A. M. Osborne, P. Payre, C. Peroni, H. Pessard, U. Pietrzyk, K. Rith, M. Schneegans, T. Sloan, H. E. Stier, W. Stockhausen, J. M. Thenard, J. C. Thompson, L. Urban, M. Villers, H. Wahlen, M. Whalley, D. Williams, W. S. C. Williams, J. Williamson, and S. J. Wimpenny, “The Ratio of the Nucleon Structure Functions F2N for Iron and Deuterium,” *Physics Letters B* 123, 275 (1983).

[2] M. J. Leitch, M. Brooks, T. Carey, G. Garvey, D. Lee, P. McGaughey, J. Moss, B. Park, J.-C Peng, P. Reimer, W. Sondheim, N. Thompson, D. Isenhower, M. Sadler, R. Towell, D. Geesaman, S. Kaufman, M. Makins, B. Zeidman, C. Brown, B. Cooper, G. Petit, X. He, B. Lee, D. Kaplan, P. Kirk, Y. Wang, Z. Wang, M. Beddo, T. Chang, G. Kyle, V. Papavassiliou, J. Webb, T. Awes, P. Stankus, G. Young, C. Gagliardi, B. Tribble, E. Hawker, D. Koetke, and P. Nord, “NUSEA—Measurement of the Asymmetry in the Light-Antiquark Nucleonic Sea,” *Physics Division Progress Report, January 1, 1995–December 31, 1996,* Los Alamos National Laboratory Report LA-13355-PR (1997), pp. 96–99.

3. Project Descriptions

Physics Division, in collaboration with the Dynamic Experiments (DX) and Applied Theoretical and Computational Physics (X) Divisions, conducts joint research activities with scientists from the premier All-Russian Institute of Experimental Physics (VNIIEF), which is the Russian counterpart to Los Alamos. These joint projects apply VNIIEF's unique capabilities to fundamental problems in high-energy-density science. Shown here is the team that performed the first High-Energy Liner experiment in Sarov, Russia. This experiment used a disk-explosive magnetic generator to implode a 1-kg, ~50-cm-diameter aluminum liner at velocities above the upper limit of two-stage light gas guns. This was the largest liner ever tested using advanced diagnostics.

BIOPHYSICS (P-21)

MRIVIEW: An Interactive Tool for Brain Imaging

D. Ranken [(505) 665-1781] (CIC-12) and J. S. George (P-21)

MRIVIEW is a software tool for viewing and manipulating volumetric magnetic resonance imaging (MRI) head data, and for using this data as an anatomical reference in studies of brain function. MRIVIEW supplies methods for reading in raw MRI data, viewing this data in either two or three dimensions, segmenting structures in the data, reconciling coordinate systems between the MRI data volume and data obtained from brain functional modalities, and viewing combinations of anatomical and functional information. MRIVIEW has three basic operating modes: a two-dimensional (2-D) mode for viewing and segmenting MRI slice data; a restricted three-dimensional (3-D) mode used for coordinate reconciliation; and a 3-D model-viewing mode.

In the 2-D mode, the MRI data volume is viewed as a series of slice images in one of the three standard orientations (sagittal, coronal, or axial). The user can page through these images eight at a time. A wide range of structure segmentation methods can be accessed while operating in the 2-D mode. These segmentation methods range from user-guided slice-by-slice flooding for labeling structures of interest, to an automatic volumetric method incorporating 3-D morphological and flooding operations.

In the 3-D model-viewing mode, MRIVIEW provides methods for generalized viewing and manipulation of 3-D MRI data volumes, and for combining these volumes with geometric models or volumes containing functional data. In this mode, the user can interactively rotate, translate, select cut planes, and perform other manipulations on a coarse model in a small graphics window, and then have the program draw a high-resolution rendering of the model (or models) in a larger graphics window. The display properties of each of these objects, such as color and rendering method used, can be manipulated independently. A variety of methods are provided for creating combined displays of MRI volumes and geometric models. The model viewer can also be used to make movies of objects in the system while they are being systematically rotated or cut by a moving cut plane.

MRIVIEW is written in IDL (Interactive Data Language), a product of Research Systems, Inc. IDL is a scientific programming language that provides a wide range of tools for data analysis and visualization, as well as features for developing graphical user interfaces. These tools work on UNIX workstations and PC and Macintosh platforms. IDL has a data parallel syntax, enabling manipulation of multidimensional arrays using arithmetic and logical operators. IDL also provides an efficient interactive mode for exploration and prototyping, as well as compiled operation for increased efficiency.

Megan: A Software Package for MEG and EEG Analysis and Visualization

E. Best [(505) 665-6187] (CIC-12) and J. S. George (P-21)

Neural electromagnetic (NEM) methods (magnetoencephalography [MEG] and electroencephalography [EEG]) allow noninvasive study of neuronal activity in the brain by measuring the magnetic field outside the head or the electric potential on the scalp. For decades, EEG (and more recently MEG) have been employed for investigating the temporal dynamics of neural population activity. The more recent use of NEM techniques for localizing current sources within the brain creates additional technical and analytical requirements. We have developed the software package MEGAN in response to the requirements for reliable signal processing, data visualization, source localization, and temporal analysis capabilities, as well as a convenient user interface, with the intent of making it available to the brain mapping community.

MEGAN currently handles MEG data from several sensor systems and is being extended to accept user-written modules to read data from other systems and to provide full support for EEG data. It supports both continuous and averaged evoked-response data. Continuous data may consist of spontaneous activity or may contain embedded sensory or behavioral responses; MEGAN provides capability for retrospective averaging relative to a stimulus or response record. This capability facilitates experimental paradigms that employ rapid or complex designs that produce temporally overlapping responses. MEGAN provides a rich variety of visualization options for selecting epochs of spontaneous data, data conditioning, and viewing of the data in a variety of forms, for example as field distributions or as waveform displays. All of the forms of data that MEGAN handles can be written to our standard netMEG file, a flexible, extensible, self-documenting, and highly portable file, written using the netCDF format. We have developed a code to read the netMEG file into programs written in C, Fortran, MATLAB and IDL. MEGAN is written in IDL, which has many advantages as a development and interactive runtime environment.

Imaging Brain Function with Magnetoencephalography

R. H. Kraus, Jr.
[(505) 665-1938], M. Espy, A. Matlochov, L. Atencio, and P. Ruminer (P-21)

Our project's goals are to develop, test, and evaluate sensor systems, numerical techniques, and computational models for functional imaging of the human brain using MEG. MEG measures a direct physical consequence of neuronal currents, with millisecond temporal resolution comparable to the temporal dynamics of the brain activity to be measured. In contrast, positron emission tomograpny (PET) and functional magnetic resonance imaging (fMRI) measure hemodynamic changes secondary to neuronal activity and are limited by the relatively sluggish vascular response to neuronal activity. Our project exploits Los Alamos-patented superconducting imaging technology to develop a high-performance whole-head MEG sensor array, combined with flux-locked loop approaches to noise reduction, advanced approaches to the electromagnetic forward and inverse problems, and computational models of brain anatomy derived from anatomical MRI. The high temporal resolution of MEG is particularly important for studying neurological disorders such as epilepsy in which temporal information is of major diagnostic value, and for fundamental studies of synchronization and oscillatory brain activity. This project benefits from collaborations with the University of New Mexico School of Medicine, the Albuquerque VA Medical Center, and Good Samaritan Hospital in Los Angeles, which are focused on clinical applications of MEG. This project has resulted in a number of applications for superconducting quantum interference devices (SQUIDs) in nonbiological Department of Energy (DOE) missions, including the DOE/Defense Program Enhanced Surveillance Program.

SQUID Microscope for Nondestructive Evaluation

M. A. Espy [(505) 665-6218], L. Atencio, R. H. Kraus, Jr., and A. Matlachov (P-21)

We have designed a SQUID microscope for use in the Enhanced Surveillance Program's nondestructive evaluation of the nuclear weapons stockpile. This microscope provides the unique ability to detect and characterize material defects and features deep within a component, even through numerous intervening layers of various materials. The development and testing of this microscope is discussed in detail in a research highlight in Chapter 2.

Bayesian Inference Applied to the Electromagnetic Inverse Problem

D. M. Schmidt [(505) 665-3584], J. S. George, and C. Wood (P-21)

To address the difficulty of estimating current distribution in the brain from surface EEG and MEG measurements (the so-called electromagnetic inverse problem), we have developed a new probablilistic approach based on Bayesian inference. Instead of aiming for a single "best" solution, our approach estimates the probability distribution of solutions upon which all subsequent inferences are based. This approach emphasizes the multiple solutions that can account for any set of surface EEG/MEG measurements. This work is described in detail in a research highlight in Chapter 2.

Optical Imaging of Neuronal Population Activity

D. Rector [(505) 665-6230] and J. S. George (P-21)

Optical imaging techniques can provide microscopic-level information about the individual and collective behavior of neuronal populations. We are developing an advanced image probe and digital acquisition system for high-performance functional neural imaging based on intrinsic light scattering signals. Two methods of reflectance mode illumination are being explored for fluorescence and polarized-light measurements. The system will incorporate an acousto-optic tunable filter to illuminate tissue with specific wavelengths for spectroscopic measurements. Our preliminary studies in the hippocampus and medulla have demonstrated several different optical changes associated with neural activation, including fast light-scattering changes concurrent with neural swelling and electrical transmission, and slower changes in light absorbence associated with hemodynamic coupling to metabolic demand.

Time-Resolved Photon Migration Tomography and Spectroscopy

J. S. George [(505) 665-2550] and D. Rector (P-21)

We are combining advanced illumination and time-resolved imaging strategies with computational models to develop optical methods for tomographic imaging and localized spectroscopy in scattering media. The sensitivity of light to physiological and biochemical parameters can provide information about the state and function of biological tissues not accessible by other techniques. This work exploits a novel photon-counting imager developed at Los Alamos for remote imaging applications. The detector is coupled to a light-collecting fiber-optic bundle detector system to measure the arrival time history and amplitude of the transmitted light emerging from many locations over the surface of the scattering medium. Time-resolved data are used to reconstruct the absorption and scattering properties of tissues using an iterative, model-based reconstruction procedure employing adjoint differentiation and gradient descent.

Single Molecule Detection

A. Castro [(505) 665-8044] (P-21)

Our efforts in the area of single-molecule detection and spectroscopy focus on the development of novel methods for the ultrasensitive detection and analysis of biological molecules and their applications to molecular biology and medical diagnosis. Recent developments include the implementation of a technique for the rapid, direct detection of specific nucleic acid sequences in biological samples without the need for enzymatic amplification. This method is based on a two-color, single-fluorescent-molecule detection technique. The basis of our approach is to monitor for the presence of a specific nucleic acid sequence of bacterial, human, plant, or other origin.

The nucleic acid sequence may be a DNA or RNA sequence, and may be characteristic of a specific taxonomic group, a specific physiological function, or a specific genetic trait. The detection scheme involves the use of two nucleic acid probes with complementary sequences to the DNA target. The two probes are labeled with two different fluorescent dyes. The probes are mixed in the sample under investigation, and, if the target is present, both probes bind to the target. The sample is then analyzed by a laser-based ultrasensitive fluorescence system capable of simultaneously detecting single fluorescent molecules at two different wavelengths. Simultaneous detection of the two probes signifies the presence of a target molecule. We have applied this method to the detection of specific sequences of DNA from a variety of sources. Most notably, we have demonstrated the detection of DNA from *Bacillus anthracis* at trace concentrations and in the presence of large amounts of unrelated DNA. *Bacillus anthracis*, the agent that causes anthrax disease, is the weapon of choice in biological warfare.

Miniature Flow Cytometer for Detecting Biological Agents

R. C. Smith [(505) 667-7931], C. Briles, and K. Wilson (P-21); and G. C. Salzman (LS-5)

In a collaboration with the Life Sciences (LS) Division, personnel from the Biophysics Group (P-21) are developing a miniature flow cytometer (MiniFCM) for the U.S. Army Chemical and Biological Defense Command at Aberdeen Proving Ground as part of their Biological Integrated Detection System (BIDS). The instrument weighs 60 lbs, has a volume of less than 2.4 ft^3, and consumes less than 250 W of power. It will be used to detect the presence of biological agents in aerosol clouds. This project has an associated cooperative research and development agreement with Bio-Rad Laboratories.

Remote Ultra-Low-Light Imaging

R. C. Smith [(505) 667-7931] (P-21)

This project, a collaboration among members of P-21 and the Nonproliferation and International Security (NIS) Division, is sponsored by the Office of Nonproliferation and National Security of the DOE and other federal agencies. Remote ultra-low-light imaging (RULLI) technology allows us to detect individual photons and measure their position and arrival time with high accuracy, opening avenues for novel applications such as detection of small objects in low Earth-orbit and measurement of foliage canopy density. This project is discussed in detail in a research highlight in Chapter 2.

Cyrax: A 3-D Laser-Mapping and Imaging System

K. Wilson [(505) 667-7823], R. C. Smith, and D. Neagley (P-21); B. Kacyra and J. Dimsdale (Cyra Technologies); and J. J. Zayhowski (MIT)

This project centered around research and development of Cyrax, a portable, 3-D laser-mapping and imaging system that can produce accurate digital models of existing structures in a simple and cost-effective manner. Cyrax, a joint effort among Cyra Technologies, Los Alamos National Laboratory, and the Massachusetts Institute of Technology (MIT) Lincoln Laboratory, earned an R&D 100 award from *R&D Magazine* as one of 1998's best innovations. This project is discussed in detail in a research highlight in Chapter 2.

Landmine Detection

K. Wilson [(505) 667-7823] (P-21) and R. Moses (T-3)

Antipersonnel landmines, which are buried dielectric scattering objects, are difficult to detect because they contain no metal. However, according to a theory developed by the Fluid Dynamics Group (T-3) of the Theoretical (T) Division, if the dielectric constant of landmines is different from the soil, then they should scatter radio-frequency energy. The U.S. Army is interested in a system that exploits this factor because it would use less power and be lighter than ground penetrating radar systems. In support of an Army contract exploring such a system, P-21 measured the impedance changes due to landmine simulants to verify the T-3 theory. The measured results were not significantly different from the theoretical model except for antenna-sized holes and rises. Such holes and rises caused more complex interaction than the simple one-dimensional (1-D) model could assess. Height variations of the measuring equipment need to be corrected by an algorithm, also developed in T-3, to increase contrast or recognition of buried dielectric objects. Although the results showed promise, the signals are very small, registering as changes of a few percent in the antenna impedance. The background changes are only slightly less. More effort will be required to produce a system that has a lower rate of false-positive detections.

Advancing X-Ray Hydrodynamic Radiography: Multipulse X-Ray Detectors

K. Albright [(505) 667-0617] (P-21)

The second axis of the future dual-axis radiographic hydrotest facility (DARHT II) has radiographic imaging requirements that can not be met with traditional methods of rotating-mirror film or single-frame intensified charge-coupled device (CCD) cameras. Two difficult problems that imaging techniques must overcome on DARHT II are gamma-ray scatter from thick high-Z targets and issues associated with high energy per pulse. The extent of these problems can be lessened with improved x-ray detectors. P-21 has identified CCD sensor technology that provides on-chip storage of multiple frames, leading to a much higher effective frame-rate than a conventional sensor. A system using this technology may achieve 100 ns per frame and capture 4 to 10 sequential frames at specified times of interest. P-21 is also developing a second approach that will use a parallel array of custom solid-state sensor/analog storage chips to record at 5 ns per frame and store up to 1,000 frames of data. A prototype system with forty channels is being developed to test this concept.

Structural Genomics

J. Berendzen [(505) 665-2552] and L. Flaks (P-21); J. Newman, M. Park, T. Peat, G. Waldo, and T. C. Terwilliger (LS-8)

Modern molecular biology has developed tools for rapidly determining the complete sequence of DNA bases of an organism, known as its genome. With this revolution firmly launched, P-21 personnel are working with LS Division to solve the 3-D structures of the proteins the DNA encodes. This work is described in detail in a research highlight in Chapter 2.

HYDRODYNAMIC AND X-RAY PHYSICS (P-22)

Nuclear Weapons Archiving Project

K. Croasdell [(505) 667-2483] (P-22)

The role of the Hydrodynamic and X-Ray Physics Group (P-22) in the Nuclear Weapons Archiving Project centers on four major tasks. First, we are involved in collection and re-analysis of data from past reaction history experiments at the Nevada Test Site (NTS). P-22 has re-analyzed the reaction history for 20 to 25 past NTS events per year since fiscal year (FY) 94. These include experiments related to a variety of weapon systems, including W-78, B-61, W-76, W-80, and W-88. The FY99 effort should result in the re-analysis of about the same number of events. In FY98 we re-analyzed four events not directly related to a stockpile device, but important to weapon physics issues, and more re-analysis of this type will be required in FY99. All data are placed on the Weapons Archiving and Retrieval Project (WARP) system in the Computational Science Methods Group (XCM) for use by the weapons community.

Our second major task is experimental procedure documentation and training. In FY98, subject matter experts from P-22 worked with Bechtel personnel to videotape procedures and “lessons learned” for fielding the reaction history experiment. These classified tapes are currently managed by P-22. In addition, over the past two years we reviewed, updated, and expanded a glossary of terms that relate to weapons testing. This glossary will also reside on the WARP database in XCM. Work has also continued on the electromagnetic pulse (EMP) experimental report procedure handbook, and our efforts continue toward establishing a contemporary computing platform for production software relating to the reaction history experiment.

Our third major task is the collection and analysis of data from past advanced diagnostics experiments. To facilitate research and categorizing the special experiments fielded by P-22 and its predecessors during the testing years, we have enlisted the help of a retiree who was employed in the P-22 anchor station where the advanced diagnostics were recorded. The documentation from these advanced diagnostics is currently being retrieved and sorted to ensure that future re-analysis of these experiments will be possible.

Finally, our fourth major task is the completion of physics reports on the most recent NTS events. Event physics reports are proving to be difficult to prepare, although the reports for the Divider and the Whitefaces experiments are nearly complete because two diagnostic physicists who were involved in fielding the experiments are preparing the reports (both are currently retired). Other reports have been given lower priority because the physicists that fielded them are currently involved in higher-priority contemporary experiments assigned to P-22.

Pegasus Pulsed-Power Facility

D. Bartsch [(505) 667-9977] (P-22)

From January 1997 to the present, we fired approximately 40 shots at the Pegasus Pulsed Power Facility. Some of these shots were in the high voltage mode, in which an array of detonators is used to punch through an insulating layer to reach current levels up to 12 MA. These shots addressed a wide variety of physics, technology development, and material property issues in support of the Weapons Program. Physics issues addressed during the past two years of Pegasus shots include geometric- and inclusion-disruption of shocks in materials, and ejecta studies. Technology studies include a variety of liner stability shots with seeded instabilities, as well as a shot series to develop an impactor-driver liner system for multimegabar shock studies on Pegasus and, once it is operational, Atlas. Several shots have been used to develop a pyrometry technique for measuring the strength of materials undergoing the high-strain and high-stain-rate of a cylindrically imploding liner system.

A variety of experiments were conducted to address material-property issues, including the Megabar, High-Strain-Rate, and Liner Stability experiments. The Megabar experiment focused on developing a composite liner with a high-density impactor layer for shock generation on Pegasus at levels up to ~6–7 Mbar. The third shot in this series, which used a platinum impactor, reached the required velocity and was diagnosed with pins and x-ray radiography to hold together during the radial run-in. Incipient Bell-Plessett instability may have been observed. For these liners, the Pegasus driver was run at maximum operating voltage and current, and the liner was designed to run at maximum velocity consistent with an unmelted impactor. This work feeds into the development of Atlas liners, and it also applies to the high-density impactor, which scales to tens of megabars on Atlas.

The High-Strain-Rate experiment used the convergence effects of a cylindrical liner implosion to measure material strength properties at strains of over 100% and strain rates of up to 10^6 on sample materials such as aluminum driver liners. Work done in distorting the sample layer against the yield strength of the material heats the sample. The temperature rise was observed with multichannel pyrometry—a diagnostic under development for use on these experiments as well as for other Los Alamos activities. Initial shots have given a data point for 6061-T6 aluminum, a material for which there is some existing data, but additional work on configuration of the liner and diagnostic is in process to obtain clean data during the entire implosion. Other materials will be studied on Pegasus and this activity will carry over to Atlas.

The Liner Stability experiment was conducted in collaboration with Russians from the premier All-Russian Institute of Experimental Physics at Arzamas-16 (VNIIEF) to study the effects of material strength on liner stability. Two shots were designed and fielded in conjunction with an extensive liner-stability series to study the effects of seeded instabilities. This is a critical issue for Atlas because we need to know the initial smoothness required for liners to achieve useful implosions. Two more shots will be done in collaboration with the Russians early in FY99.

Diagnostics for Liner Stability Experiments at Pegasus

D. A. Clark [(505) 667-5054], D. V. Morgan, P. J. Rodriguez, and L. Tabaka (P-22); G. Rodriguez (MST-10); and collaborators from X and DX Divisions and Bechtel Nevada

We performed a series of experiments to compare imploding cylindrical liner performance with magnetohydrodynamic (MHD) modeling at the Los Alamos Pegasus II pulsed-power machine. Liner instability growth originating from initial perturbations machined into the liner was observed with high resolution. Three major diagnostics were used: radiography, VISAR (which stands for velocity interferometry for a surface of any reflector), and fiber-optic impact pins. For radiography, three flash x-ray units were mounted radially to observe liner shape at three different times during the implosion. Liner velocity was measured continuously with VISAR for the entire distance traveled in two experiments. Optical impact pins, distributed axially and azimuthally in the central diagnostic assembly, provide a high-resolution measure of liner symmetry and shape near the end of travel. Liner performance has compared well with predictions.

Composite Liner, Multimegabar Shock-Driver Experiments at Pegasus

J. C. Cochrane, Jr. [(505) 667-1227], R. R. Bartsch, D. A. Clark, D. V. Morgan, W. E. Anderson, J. L. Stokes, and L. R. Veeser (P-22); H. Lee, R. L. Bowers, and W. L. Atchison (X-PA); H. Oona (DX-3); and collaborators from Bechtel Nevada

Multimegabar shock driver development involves a series of experiments in support of the Los Alamos High-Energy-Density Experiments program. The purpose of these experiments is to develop techniques to impact a uniform, stable, composite liner on a high-Z target to produce a multimegabar shock for equation-of-state (EOS) studies. Aluminum liners with a thin layer of platinum on the inside are used to increase shock-induced pressure in the target. To date, experiments have been done on the Pegasus II capacitor bank with a current of ~12 MA driving the impactor liner. The driving field is ~200 T at the target radius of 1 cm.

We have gathered data on the stability and uniformity of the imploding liner when it impacts the target cylinder, and we have done three experiments with emphasis on liner development. Shock pressures greater than a megabar have been produced with an aluminum target cylinder. A platinum target cylinder should produce shock pressures in the 5-Mbar range. Load diagnostics for the series include radial radiography, optical impact pins, and inductive probes for current measurements.

Shock-Induced Flows in Strengthless Materials at Pegasus

D. M. Oró [(505) 665-0441] (P-22) for the Atlas collaboration

Experiments on the Pegasus II pulsed power facility are being conducted to study the evolution and flow of strengthless materials resulting from a shock in the material. Of particular interest is vorticity, jetting, and mixing induced in the materials by a shock wave passing through a nonuniform boundary. The experiments provide an important benchmark for hydrodynamics codes, and are a precursor to experiments planned on Atlas, in which the materials will be pre-ionized before being shocked. This work is covered in detail in a research highlight in Chapter 2.

Atlas Power Flow Development

T. McCuistian [(505) 667-7022] (P-22)

A series of ten shots was recently fired on Pegasus II to test current joints that may be used in making electrical connections on Atlas. Tests on Pegasus II were able to simulate the linear current density (A/cm) and action (fI^2 dt A^2s/cm^2) that will exist at the most demanding Atlas current joints. A total of 32 different current joints were tested at ~5 MA each. The reduced dimension of the Pegasus II current joints relative to the Atlas current joints provided comparable linear current densities (~100 kA/cm) and actions ($\sim 6 \times 10^4$ A^2s/cm^2) to the relevant Atlas joints. Current joints were tested between aluminum, alodined aluminum, silver-plated aluminum, copper, and stainless-steel flanges. Some current joints were made using gasket materials of indium, soft aluminum (Al 1100), annealed copper, and stainless steel. Various geometries such as knife-edge joints, current nibs (which are regions of small surface contact area between parallel surfaces), and contact regions at various angles were also tested.

Isentropic Compression Experiments at VNIIEF

L. Veeser [(505) 667-7741] (P-22)

Los Alamos National Laboratory and VNIIEF are performing a set of joint experiments to explore the conductivity and possible metalization of argon and krypton compressed to up to five times normal solid density. These materials remain monatomic at high compressions; consequently, their behavior involves their atomic structure, and it is not complicated by molecular changes. The experiments use a magnetic field of several megagauss, generated by a Russian MC-1 generator, to compress a metallic tube containing solidified argon or krypton. A probe in the center of the tube measures the electrical conductivity to the sample tube walls, and a 70-MeV betatron serves as an x-ray source for radiographic measurements of the compression at three times near-peak compression. Several of these experiments for argon compressed to between four and five times solid density, roughly 5-Mbar pressure, indicate a conductivity in the range of order 10 Ω^{-1} cm^{-1}, well below that of a metal. For krypton, similar compression shows a conductivity of 1,000 Ω^{-1} cm^{-1} or more, indicating likely metalization. At slightly lower compressions, a little under four times normal solid density and ~4-Mbar pressure, the argon conductivity remains about the same while that of krypton appears to have dropped significantly. We are presently analyzing and interpreting the data from several shots that occurred in the summer of 1998.

Russian Collaboration on Magnetized Target Fusion

J. Benage [(505) 667-8900], B. Anderson, R. Bartlett, G. Idzorek, and L. Tabaka (P-22)

In August 1998 a team of physicists, engineers, and technicians from P-22, the Dynamic Experimentation (DX) Division, and Bechtel Nevada, traveled to Sarov, Russia, to participate in a series of experiments at VNIIEF. These experiments focused on measuring the properties of target plasmas suitable for implosion in magnetized target fusion experiments. The focus of the experiments was to produce a high-temperature, long-lived plasma suitable for a magnetized target implosion experiment. The goal of the Los Alamos team was to field diagnostics to determine three characteristics of these plasmas: the temperature of the plasma, the lifetime at high temperature, and the levels and types of impurities in the plasma. To determine the temperature and lifetime, several sets of silicon diode arrays with x-ray filters selected for the expected temperature range and located at appropriate positions were used. For a measurement of the impurities, a time-resolved ultraviolet (UV) spectrometer was fielded. Our efforts in these experiments were successful. We were able to obtain good diode signals for nearly all channels, and we will be able to obtain lifetime information and temperature information. The time-resolved spectrometer fielded by DX Division also obtained some excellent spectroscopy data. The spectroscopy data, along with the diode signals, should allow us to determine a reasonable temperature–*vs.*–time curve for the plasma. This data will be very important for determining whether these plasmas are appropriate as a target plasma for implosion and whether further investigation is required.

Cerenkov Detection of Deuterium-Tritium Fusion Gamma Rays from Inertial Confinement Implosions

J. M. Mack [(505) 667-3416], S. E. Caldwell, H. Hsu, and C. S. Young (P-22)

As fusion ignition conditions are approached using the National Ignition Facility (NIF), independent high-bandwidth fusion burn measurements become essential. Neutron time-of-flight methods are being pursued and should be complemented by direct and indirect gamma-ray methods. New analyses of gamma measurements from implosions at the Nova facility indicate the likely observation of 16.7-MeV gamma-rays produced as a deuterium-tritium (D-T) reaction byproduct. Related neutron/photon Monte Carlo calculations suggest that the number of direct (16.7-MeV) and indirect (neutron-induced) gammas are comparable and consistent with experimental results. This supports the proposition that neutron-induced and 16.7-MeV gamma rays were observed using photo-conductive detectors (PCDs). However, PCD systems are limited to 45-ps time resolution; systems with better than 20-ps resolution are needed.

Another means of detecting 16.7-MeV D-T fusion gamma rays is the conversion of these photons to electrons and eventually to (optical light) Cerenkov photons. Fast-gas Cerenkov detection system designs are being developed and optimized for use on NIF targets. These designs are intended to achieve faster detection speeds (10–20 ps) and provide improved energy selectivity for detecting 16.7-MeV gamma-rays. We have recently developed capability to perform *ab initio,* time-dependent Monte Carlo simulations of photon/electron/Cerenkov cascade generation and transport in generalized 3-D geometry with geometrical optics included. Such studies provide information critical to our end-to-end design analyses.

Fabrication Defect Studies

S. E. Caldwell [(505) 667-2487] (P-22); S. R. Goldman (X-PA); M. D. Wilke (P-23); W. W. Hsing (Lawrence Livermore National Laboratory); D. C. Wilson (X-TA); and G. T. Schappert, S. B. Boggs, S. C. Evans, T. J. Sedillo, and P. J. Walsh (P-24)

This project studies the propagation of nonplanar shock waves using the Nova laser at Lawrence Livermore National Laboratory. In our experiments, shocks are ablatively driven by 190-eV radiation from a Nova hohlraum and imaged in two dimensions using time-resolved x-ray radiography. In our first experiment, two pieces of medium-density copper-doped beryllium [Be(Cu)] at 2.0 g/cc were separated by a 15-µm layer of aluminum at 2.7 g/cc. The shock motion was parallel to the aluminum layer. The radiographs demonstrate that the presence of the higher-density aluminum retards the velocity of the shock traveling within the Be(Cu) some distance away from the interface. The lateral extent of the perturbation grows with time. When the aluminum is replaced with a low-density plastic (CH) (1.1 g/cc), the opposite effect is seen, *i.e.*, the shock front within the Be(Cu) near the CH travels ahead of the shock front more distant from the CH.

This effect must be taken into account in the design of inertial confinement fusion (ICF) capsules, which may have joints or other defects, because a small-area defect can lead to a large-area perturbation in the shock front. The quantitative results of this program have been used by the Applied Theoretical and Computational Physics (X) Division to evaluate the calculational capabilities of two hydrodynamics codes.

Integrated Experiments on Nova and Z

R. Chrien [(505) 667-1674], G. Idzorek, and S. Caldwell (P-22); B. Wilde, G. Magelssen, F. Swenson, and D. Wilson (X-TA); and D. Peterson and W. Matuska (X-PA)

We are conducting a series of integrated experiments using Livermore's Nova laser and Sandia National Laboratory's Z pulsed-power facility. In these experiments, we have created an experimental test bed for radiation hydrodynamic calculations that is producing weapons-relevant results. The results are being used to test and guide new code development in the Advanced Strategic Computing Initiative (ASCI) Program. Significant new diagnostic capabilities are being developed in the course of this work. The success of these experiments adds a major new thrust to the use of above-ground experiments (AGEX) facilities in the Science-Based Stockpile Stewardship (SBSS) Program.

Subcritical Experiments at NTS

L. R. Veeser [(505) 667-7741] for this DX Division/Physics Division collaboration

In 1997 and 1998, three major subcritical experiments were fielded at the NTS by DX Division in collaboration with Physics Division, other Los Alamos Divisions, Sandia National Laboratory, and Lawrence Livermore National Laboratory. The first two experiments, called Rebound and Stagecoach, focused on the plutonium EOS. The third experiment, called Cimarron, focused on the ejecta produced when a shock in the plutonium releases into the surrounding vacuum. These experiments are discussed in detail in a research highlight in Chapter 2.

Optical Impact Pins on the Cimarron Subcritical Experiments at NTS

D. A. Clark [(505) 667-5054], P. J. Rodriguez, and G. D. Allred (P-22); and collaborators from Bechtel Nevada.

P-22 mounted optical impact pins on the Cimarron subcritical experiments at the NTS to measure the free-surface velocity of the material under study. The pins consisted of a length of 80-μm optical fiber with one end mounted in a 0.029-inch-diameter stainless steel tube that was between 0.25 inch and a few inches in length. The tube provides rigidity and alignment for the glass fiber. When a fast-moving surface strikes the end of the fiber pin, a shock is induced into the glass, increasing its temperature and generating light. A photodetector and transient recorder at the output of the fiber pin measured the time of arrival of the light pulse and its amplitude. Detection and recording of the light pulses was done in an instrumentation trailer above ground. The fiber optic path length between the trailer and the device underground was about 1 km.

Optical pins are used on various experiments because of their simplicity, flexibility, accuracy, and ability to produce a time history if several subsequent shocks are induced into the pin. They are very compatible with rigid requirements for environmental seals and placement geometry associated with the subcritical experiments. A challenging part of preparations for the subcritical experiment was the successful development of tiny welded containment tubes, or “pin wells,” that meet transportation and environmental-seal requirements. The pin wells provide physical support and positioning for the optical pins. Some of the wells have small-radius bends, but the flexible fibers can be easily inserted into the wells.

Optical pins were also mounted and tested on four “full up” surrogate packages tested at Los Alamos firing sites, and they were used to support development of other diagnostics, such as VISAR and pyrometry, on several small shots designed for that purpose. Information provided by the optical pins on all of these recent tests has been of high quality and has provided valuable support of other diagnostics mounted on the devices.

Infrared Pyrometry

D. Holtkamp [(505) 667-8082] and B. Wright (P-22)

During FY98, P-22 performed a number of experiments in optical pyrometry of shocked metal surfaces. Two seven-channel optical pyrometers were fielded during the Stagecoach subcritical experiment in March, resulting in new data on the temperatures of shock-compressed nuclear material. These pyrometers used a combination of liquid-nitrogen-cooled and room-temperature detectors to measure surface radiances between 1 and 5 μm in wavelength. The remote liquid nitrogen fill system worked well even in the harsh, difficult underground environment. We also developed a new, much more sensitive pyrometer for the Cimarron event that uses liquid-nitrogen-cooled and room-temperature detectors, but also extends the wavelength range to visible wavelengths using sensitive photomultiplier detectors. This extension into the visible is an important advance because it improves the accuracy of temperature measurements dramatically.

We also performed two experiments using very low-temperature pyrometers on Pegasus. In two experiments in FY98, High Strain Rate 2 and 3, we improved our understanding of how to successfully perform very-low-radiance temperature measurements (corresponding to a temperature rise threshold of less than 100°C) in the difficult experimental environment of an imploding liner with very high pulsed currents coursing through it. We have obtained good data and expect to obtain even better results in the near future.

The 1997 Dirac High-Magnetic-Field Experiment Series at Los Alamos

D. A. Clark [(505) 667-5054], P. J. Rodriguez, L. J. Tabaka, and K. C. Forman (P-22); J. D. Goettee, C. Mielke, and D. G. Rickel (DX); and W. Lewis and B. R. Marshall (Bechtel Nevada)

During the summer of 1997, a series of high magnetic-field experiments was conducted at Los Alamos National Laboratory. It was the second in the series named for P. A. M. Dirac, whose contributions to quantum theory are basic to the physics under study. The experiments included collaborators from Japan, Russia, Australia, and several U. S. laboratories, including Louisiana State and Florida State Universities and the National High Magnetic Field Laboratory. Four experiments using Russian-built MC-1 flux compression generators (FCGs), which can reach fields as high as 10 MG, and four smaller strip generator experiments at fields near 1.4 MG were completed. P-22 recorded data for microwave and fiber-optic experiments, participated in the design and setup of several experiments, and was responsible for measurement of the high magnetic fields.

Two of the MC-1 FCG shots focused on microwave magnetoresistance measurements of wide-parabolic quantum-well and high-temperature superconducting samples at temperatures less than 2°K. The wide-parabolic quantum-well data found experimental evidence of 2-D electron gas behavior that had been predicted long ago. The high-temperature superconducting experiments looked for the reappearance of superconductivity in $YBa_2Cu_3O_7$ semiconductor samples at magnetic fields above 800 T. Other experiments on the microwave shots included a search for metal-semiconductor-insulator transitions in molecular conductors. The other two MC-1 FCG shots focused on magnetization measurements of Mn_{12} and MnF_2. A Faraday rotation technique was used to make the magnetization measurement for the Mn_{12} sample. Other experiments were mounted on the MC-1 shots below the liquid helium cryostat and operated at approximately 77°K. They included spectrographic absorption in ReCl and MoCl, a study of AuGe for thermometry, reflectivity of GaAs at 630 nm, and optical transmission of cobalt-60. Faraday rotation in quartz crystals was the primary technique for measuring the magnetic field for each MC-1 shot. Inductive pickup probes were installed in all devices to measure the fields electrically. The entire series was very successful, and excellent data were returned from almost all experiments and diagnostics.

Big G

G. Luther [(505) 667-3178] (P-22)

This project aims at redetermining the Newtonian gravitational constant, G. During the year, the project facility was relocated from the end of Frijoles Mesa to a location more central to the Laboratory. While rebuilding the apparatus, we will add several improvements. A new control and analysis program is being implemented, and a bifillar suspension system has been designed to reduce the dependence on temperature control and lack of vibration. In addition, a new small-mass system is being constructed. A prototype of this system has been built and tested, and we are constructing a redesigned vacuum chamber to contain the system.

Single-Photon Ionization of Helium by Compton Scattering and the Photoelectric Effect

D. V. Morgan [(505) 665-6679] and R. J. Bartlett (P-22)

Helium is the simplest neutral atomic system in which electron-electron correlation effects can be studied. The existence of doubly-ionized helium from interaction with a single photon results directly from these correlations for both photoabsorption and inelastic (Compton) scattering. However, the final states associated with double ionization in these two processes differ considerably. For photoabsorption, there is a high probability that the photon energy is transferred almost entirely to the primary photoelectron, while for Compton scattering most of the initial x ray energy is given to the scattered x-ray, and hence the ejected electrons are comparatively slow. At x-ray energies between 4.5 and 12 keV, the strongly energy-dependent photoionization cross section falls rapidly, whereas the Compton scattering cross section is a slowly increasing function of energy with a “crossover” at approximately 6.3 keV. Theoretical calculations for the double-to-single ionization ratio in the crossover region are performed independently because of the intrinsic difference between Compton scattering and the photoelectric effect.

We have developed a technique for distinguishing the helium ionization states caused by Compton scattering from those caused by the photoelectric effect by observing the different recoil energies of the helium ion associated with the two processes. Using this technique, we have determined the ratios of the double-to-single ionization cross sections of helium for the photoelectric effect and Compton scattering for several energies between 4.5 and 12.0 keV, and we have compared these results with previous measurements and theoretical calculations.

Interferometry for DARHT Plasmas and Hydrodynamics

M. Wood [(505) 665-5-6572], B. Wright, D. Fulton, and J. Studebaker (P-22)

The future DARHT facility is a large radiography facility based on the bombardment of metal targets with high-energy electron beams. To ensure operation within the proposed specifications, we are characterizing the products of a relativistic beam-target interaction. The beam-target interaction, necessary for producing the gamma rays for radiography, also produces plasmas and rapid hydrodynamic motion of targets under conditions that are very unfavorable to measurement. P-22 has successfully fielded two interferometric diagnostic systems at different frequencies to address two issues that affect the success of the DARHT program. These two issues are (1) the question of whether or not ions generated promptly by the beam-target interaction adversely affect the focusing of the electron beam, and how to alleviate any problems that do exist; and (2) the question of whether or not the hydrodynamic expansion of the target will interfere with subsequent shots nearby on the same target, and how to fix this problem if it exists.

The first interferometric system is a Mach-Zehnder configuration at the microwave frequency of 94 GHz. This system was fielded on both the Integrated Test Stand (ITS) machine at Los Alamos and the Experimental Test Accelerator (ETA-II) at Livermore. ITS operates at approximately 5.5 MeV with a current of 4 kA, and ETA-II operates at about 6.5 MeV with a current of 2 kA. Both of these machines are lower-energy accelerators for investigating the physics that will affect the final DARHT design. Using this measurement system, we were able to observe the early temporal evolution of the plasma coming from beam-target and laser-target interactions with the intent of helping to answer the question of whether ions generated by the interaction affect the focusing of the electron beam. Measured phase shifts and amplitude diminution at two different locations have enabled us to distinguish primary (relativistic) and secondary electron populations during the electron beam by changing the polarization plane of the microwaves. Furthermore, distinct signatures of both fast (low-Z) and slow (high-Z) ions have been observed in a number of different types of targets after the departure of the electron beam. These observations have led to estimations of the ion density and geometry during the experiment. Late time observations indicate the beginning of the hydrodynamic expansion of the target, with increased collisionality due to the presence of neutral atoms.

To monitor the later-time hydrodynamic expansion of the targets, we have constructed a HeNe-based Michelson interferometer system for use on ITS, and consulted in the design and construction of a HeNe-based Fizeau, 2-D interferometer on the ETA-II machine. With the diagnostic on ITS, we have observed the expansion of the front of hydrodynamically driven material, and measured expansion velocities in close agreement with previous measurements performed by P-22. These measurements have also provided excellent benchmarks for X Division to model the hydrodynamic expansion. Their modeling shows good agreement with local temperature predictions, helping to provide the distinction between several choices of ionization models.

NEUTRON SCIENCE AND TECHNOLOGY (P-23)

The LANSCE Rotor Ultracold Neutron Source

R. Hill [(505) 667-8754] (P-23)

A source of ultracold neutrons (UCN) produced by the technique of Doppler-shifted elastic scattering has been placed into operation at the Los Alamos Neutron Science Center (LANSCE) Manual Lujan Neutron Scattering Center (MLNSC) by the Neutron Science and Technology Group's (P-23's) Weak Interaction Team. A beam of cold neutrons with velocities, V_n, of about 400 m/s is directed onto a package of crystals moving with a velocity, V_c, in the neutron beam direction of about 200 m/s. This is accomplished by rotating the package on the end of a 90-cm-long arm at 40 Hz and synchronizing the motion of the rotor with the proton beam so that the package arrives at the position of the beam at the time when 400 m/s neutrons are present. Under these kinematic conditions, the elastically scattered cold neutrons are Doppler-shifted down to very low velocities (corresponding to the transverse momentum components), producing storable UCN with resultant velocities less than about 8 m/s. The elastic scattering process is enhanced by Bragg scattering from the crystals which have a lattice spacing of about 10 Å, corresponding to a neutron velocity of about 400 m/s. Maximum UCN production occurs when the condition for Doppler shifting ($V_n = 2V_c$) is simultaneously met with the condition for Bragg scattering (n = 10 Å). The rotor was first used in late 1996 and achieved significant UCN production in mid-1998.

Since the MLNSC beam was operating at 20 Hz, this corresponded to a detected UCN rate of about 600 per second for a proton beam current of about 20 A. We have made improvements to the cold neutron moderator and intensities of 100 A are anticipated. The crystal package has also been improved so significant improvements in UCN production are expected.

A Low-Duty-Factor, High-Current Spallation Neutron Source

S. Seestrom [(505) 667-0156] (P-23)

We are working to develop a low-duty-factor, high-current spallation neutron source at LANSCE. This source will provide the most intense UCN source in the world, and it will also provide pulsed cold and fast neutrons. A UCN source of such intensity will allow a wide range of research, providing a new range of sensitivity for studies of the fundamental properties of the neutron, and allowing us to probe the structure of weak interactions in neutron beta decay. We will produce

UCN by using 800-MeV protons from the LANSCE accelerator to produce fast neutrons that we then moderate into cold neutrons. When these cold neutrons strike a volume of frozen deuterium in our apparatus, they cool to UCN. It takes only a few seconds to build up to equilibrium UCN in the storage bottle. The proton beam is then shut off and the shutter between the deuterium and the storage bottle is closed. This short timing is fortunate because it would be difficult to sufficiently cool the deuterium if the proton beam operated continuously. The UCN trapped during each proton beam pulse can be bled into UCN guides and transported to various experiments. LANSCE Area B is currently considered the ideal location for this source because it already has the appropriate infrastructure (*e.g.*, cooling water, power, a crane, *etc.*).

We have tested a prototype of this UCN source. First, we measured the rate of UCN production by cold neutrons incident on a solid deuterium sample at the Hahn Meitner Institute in Berlin. Based on those results, we constructed a stand-alone system and tested it at LANScE's Area C and Blue Room. The UCN production rate is about what we have predicted, and we are currently exploring how to get the UCN out of the deuterium and out of the cryostat.

Cold Neutron Radiography

T. McDonald [(505) 665-7294] (P-23)

A neutron radiography technique, which we refer to as time-gated energy-selected (TGES) radiography, has been demonstrated at the LANSCE MLNSC for producing radiographic images from only a narrow energy range of cold neutrons. Time of flight is employed to obtain a neutron pulse having an energy distribution that is a function of the neutron arrival time at the imager. The neutron imager is formed on a short-persistence scintillator and is lens-coupled to an intensified cooled CCD camera. The intensifier is gated off except during the time in the neutron pulse when the energy range of interest is present. Some materials exhibit a large change in scattering cross-sections across the Bragg cutoff energy, and material discrimination of these materials can be achieved by imaging above and below their Bragg cutoff energies using TGES radiography. We have recently assembled an improved imager for carrying out TGES radiography, which includes a high-resolution, $1{,}600 \times 1{,}600$ CCD camera and a fiber-optic-coupled, large-format 40-mm diode intensifier. The imaging system will be used in the next run cycle at the MLNSC.

Fundamental Symmetries with Trapped Atoms

A. Hime [(505) 667-0191], S. J. Brice, A. Goldschmidt, and R. Guckert (P-23); S. G. Crane, D. J. Vieira, W. A. Taylor, and X. Zhao (CST-11); and D. Tupa (P-25)

We are pursuing a measurement of the positron-nuclear spin correlation function from the beta decay of ^{82}Rb confined to a Time-Orbiting-Potential (TOP) trap. This purely magnetic trap provides a rotating beacon of spin-polarized ^{82}Rb nuclei which can be exploited to measure the parity-violating correlation as a continuous function of the positron energy and emission angle relative to the nuclear spin orientation. This project is discussed in detail in a research highlight in Chapter 2.

Quantum Computation using Cold Trapped Ions

R. J. Hughes [(505) 667-3876], D. J. Berkeland, D. Enzer, M. Gulley, M. H. Holzscheiter, D. F. V. James, P. G. Kwiat, S. K. Lamoreaux, C. G. Peterson, A. G. Petschek, V. Sandberg, M. Schauer, and D. Tupa (P-23)

Quantum computation is a new computational paradigm that is much more powerful than classical computation because it allows computing with quantum-mechanical superpositions of many numbers at once. In a quantum computer, binary numbers will be represented by quantum-mechanical states ("qubits"). We are developing a quantum computational device in which the qubits will be two electronic states of calcium ions that have been cooled with a laser to rest in an ion trap. Our work on this project is described in detail in a research highlight in Chapter 2.

Development of Algorithms for Quantum Computers

R. J. Hughes [(505) 667-3876], P. Hoyer, and J. M. Ettinger (P-23)

In 1994 it was shown that a quantum computer, using the "quantum parallelism" afforded by the superposition principle, could be used to find the prime factors of composite integers much more efficiently than with any conventional computer. Because integer factorization and related problems that are computationally intractable with conventional computers are the basis for the security of modern public-key cryptosystems, this single result has turned quantum computation from a strictly academic exercise into a subject whose practical feasibility must be urgently determined. In addition, it is of great interest to determine the class of problems that are amenable to more efficient solution on a quantum computer than on classical computers. Integer factorization is a particular instance of the more general problem of finding a "hidden" subgroup of an Abelian group, given a function that takes on constant but distinct values on the cosets of the subgroup. We have been investigating the generalization of this problem to non-Abelian groups and believe that the techniques we have developed will open up new applications for quantum computational algorithms.

Quantum Cryptographic Key Distribution Over Optical Fibers

R. J. Hughes [(505) 667-3876], G. G. Luther, G. L. Morgan, and C. G. Peterson (P-23)

The secure distribution of the secret random bit sequences known as "key" material, is an essential precursor to their use for the encryption and decryption of confidential communications. Quantum cryptography is an emerging technology for secure key distribution with single-photon transmissions: Heisenberg's uncertainty principle ensures that an adversary can neither successfully tap the key transmissions, nor evade detection (eavesdropping raises the key error rate above a threshold value). We are performing quantum cryptography over 48 km of underground optical fiber using nonorthogonal single-photon interference states to generate shared key material. Key material is built up by transmitting a single-photon per bit of an initial secret random sequence. A quantum-mechanically random subset of this sequence is identified, becoming the key material after a data reconciliation stage with the sender. The nonorthogonal nature of the quantum states ensures that an eavesdropper cannot identify the bit values in the key sequence. Our experiment demonstrates that secure, real-time key generation over "open" multikilometer node-to-node optical fiber communications links is possible. During the past year we constructed a quantum cryptography system and installed it for our sponsor in the Washington, D.C., area.

Quantum Cryptography for Secure Communications to Low-Earth-Orbit Satellites

R. J. Hughes [(505) 667-3876], W. T. Buttler, S. K. Lamoreaux, G. G. Luther, G. L. Morgan, J. E. Nordholt, and C. G. Peterson (P-23)

Cryptanalysis techniques and algorithms are advancing rapidly, and by the start of the 21st century they will necessitate the development and use of new encryption technologies to ensure secure communications to satellites. The aim of our project is to develop quantum cryptography to provide absolutely secure encryption of communications to low-Earth-orbiting satellites. We will develop and demonstrate the cryptographic technology to a stage where it can be feasibly incorporated into new satellites. During the past year, we designed, constructed, and tested a quantum cryptography system that used single-photon transmissions to create and transmit cryptographic random numbers between sending-and-receiving instruments separated by a 1-km outdoor optical path. This work is discussed in detail in a research highlight in Chapter 2. We are now planning to extend the transmission range to more than 2 km in a new system that incorporates active control to compensate for turbulence-induced beam wander, and we are developing plans for a surface-to-satellite test experiment.

Cryptographic Key Generation using Long-Baseline Radio Interferometry

R. J. Hughes [(505) 667-3876], J. E. Nordholt, S. K. Lamoreaux, J. Knight, D. M. Suszcynsky, and W. T. Buttler (P-23)

The need for secure, encrypted communications is becoming increasingly important in many areas, but the secure generation and distribution of the secret random number sequences known as cryptographic keys is an essential precursor to their use in encryption hardware and software. Existing methods of key distribution are cumbersome, impractical for many applications, and not demonstrably secure. We are developing a new technique for two parties to generate on-demand a shared secret key from simultaneous observations of the correlated radio noise from astronomical objects. These correlated radio emissions over baselines of up to several thousand kilometers are used by astronomers to study extra-galactic sources, and by geophysicists measuring continental drift rates. However, the radio emissions from the brightest radio sources can be detected with commercially available radio equipment using small antennas, and the necessary frequency and time standards are now readily available to allow the rapid generation of highly (80%) correlated raw key streams by two widely separated observers. Three stages of theoretically secure data analysis, known as advantage distillation, privacy amplification, and error correction, are used to distill a shorter, secret, error-free key. Even though an adversary may make her own observations of the same radio emissions, this three-step procedure ensures that she retains less than one bit of information about the final key. Potential advantages of this method of key generation are its convenience (couriers are not required to transport key), its guaranteed security (in contrast to the conditional security of public key distribution systems), and the compactness of the hardware required. We have constructed a system to generate key material in this way and expect to have our first results before this document goes to press.

Optical Approaches to Quantum Information

P. Kwiat [(505) 667-6173], J. Mitchell, P. Schwindt, and A. White (P-23)

Researchers in P-23 have been making great strides in the investigation of “interaction-free measurements,” in which the existence of non-transmitting objects (absorbers or scatterers) can be ascertained with arbitrarily small absorption/scattering taking place. This year we have made a complete theoretical study of the effects of losses on system efficiency, and confirmed the results experimentally. (See the research highlight on this topic in Chapter 2.) Using a fast switching system, we have produced true efficiencies of up to 73%, which is the world’s first demonstration to break the 50% limit, and demonstrated the feasibility of up to 85% efficiency. Also, we performed a series of experiments investigating the practical implementation of interaction-free "imaging," where the techniques are used to take a pixellated 1-D image of an object, again with the goal of negligible absorption or scattering. Finally, we have begun a complete theoretical treatment of the fairly complicated problem of coupling to a quantum object, such as a single atom or ion, which can be in a superposition state. We have demonstrated, for example, that the quantum state of the object can be transferred to the interrogating light, allowing the production of macroscopic entangled states of light and Schrödinger-cat states.

In related research, we have performed the world's first comprehensive test of the wave-particle duality, in which the relationship between the amount of wave-like (interference) and particle-like (definite trajectories) behavior is quantified. Using a unique tunable source of various pure, mixed, and partially-mixed states of light, we have demonstrated that, contrary to popular belief, lack of particle-like information does not necessarily imply wave-like behavior, and *vice versa*. We have also demonstrated several novel types of "quantum erasers," in which wave-like behavior can be recovered if one erases the particle-like information. Curiously, it was demonstrated that even for mixed states, where no particle-like information exists, one can still recover interference. These studies have direct relevance to the growing field of quantum information, specifically quantum computation, where proposals for error correction based on quantum erasure rely on an understanding of the phenomenon when non-pure states are involved.

Finally, we have designed and demonstrated the first all-optical implementation of a quantum circuit. Recently it was shown that all of the essential operations of a quantum computer could be accomplished using only standard linear optical elements (*e.g.*, beam splitters, wave plates, polarizers, *etc.*). In this technique, the individual bits are represented by different spatial or polarization modes of light. This summer we realized a simple optical implementation of Grover's algorithm for efficiently searching a database. In our example, a database of four elements is searched with a single query, in contrast to the classical expected value of 2.25 queries. Whereas an exact one-to-one correspondence with Grover's algorithm would require over 25 optical elements, our "compiled" version required only 11. The quantum computer is no more than an interferometer, albeit a complicated one. The difference from a genuine quantum computer with distinct entangleable registers is that the optical implementation requires a number of elements that grows exponentially with the number of bits. Nevertheless, we intend to extend our work to circuits involving several bits, and also to investigate several proposed schemes of "quantum control."

The Penning Fusion Experiment

M. Schauer [(505) 665-6014] (P-23)

The Penning fusion experiment (PFX) is an experiment and theory effort to investigate the feasibility of using Penning-trap-like devices for fusion confinement. Penning traps use static electric and magnetic fields to confine charged particles for periods lasting up to hours, but due to the nonneutral nature of the confined plasmas, the densities attainable in these devices is limited. The limiting value occurs when the repulsive force of the space charge of the plasma balances the confining force resulting from the rotation of the plasma in the external magnetic field. This is referred to as the Brillouin limit. For a pure electron plasma in a 1-T field, the Brillouin density limit is of the order of 10^{12} cm^{-3}, while for an atomic deuterium ion plasma in the same magnetic field, the limiting value is of the order of 10^9 cm^{-3}. The major goal of PFX is to demonstrate that this limiting value can be exceeded in some small volume at the trap center while preserving it when the plasma density is averaged over the entire volume of the trap.

PFX is divided into two stages. The first stage, completed in FY97, demonstrated that a dense core plasma can be attained in a nonthermal pure electron plasma through spherical focusing. Basically, electrons with a beam-like energy distribution are injected into a trap that is designed such that the electrons are focused to a spot in the center. The results of these experiments indicate a focus spot with a radius of roughly 50 µm and a peak density of nearly 40 times the Brillouin limit. The details of these data can be found in numerous recent publications (*e.g.*, T. B. Mitchell, *et al.*, *Physics Review Letters* 78, 58 [1997]; D. C. Barnes, *et al.*, *Physics of Plasmas* 4, 1745 [1997]; M. M. Schauer, *et al.*, *Review of Scientific Instruments* 68, 3340 [1997]).

The second stage of PFX was funded in FY98 and will concentrate on reproducing these results with positive ions. Due to limitations of the approach used in the first stage experiments, a quite different architecture will be used in the second stage experiments. Here, a uniform electron cloud, with density near the Brillouin limit, will be confined in a modified Penning trap, and the resulting space charge will then provide trapping for positive ions. Through careful tailoring of the vacuum trapping fields, the resulting well will produce spherical focusing for the ions. This will allow eventual use of deuterium and tritium ions for maximum fusion power, but initial work will concentrate on producing a focused plasma of hydrogen ions.

Sudbury Neutrino Observatory

A. Hime [(505) 667-0191], T. J. Bowles, S. J. Brice, A. Goldschmidt, and J. M. Wouters (P-23); M. M. Fowler, G. G. Miller, and J. Wilhelmy (CST-11); and collaborators from Lawrence Berkeley National Laboratory, the University of British Columbia at Vancouver, Brookhaven National Laboratory, Carleton University at Ottawa, the Centre for Particle Physics in Ottawa, Chalk River Laboratories, the University of Guelph, Laurentian University at Sudbury, Oxford University in England, the University of Pennsylvania, Queens University at Kingston, and the University of Washington

During the past thirty years, extensive theoretical and experimental effort has culminated in what is now commonly referred to as the solar neutrino problem, wherein the neutrino signals registered in terrestrial detectors exhibit an energy-dependent deficit in comparison to the predictions of solar models. The results yield a tantalizing hint that neutrinos possess non-zero rest masses and that mixing occurs in the lepton sector, marking evidence for physics beyond the standard model. New generation experiments are thus designed to resolve the solar neutrino problem using techniques that do not rely upon solar model calculations for their interpretation, but rather directly search for the physics manifest in neutrino oscillations.

The Sudbury Neutrino Observatory (SNO) is a real-time, solar neutrino laboratory that uses 1,000 tonnes of heavy water to carry out two basic measurements on the 8B solar neutrino flux. The charged-current (CC) interaction on deuterium can proceed only through electron-neutrino interactions. The flux and energy spectrum of electron neutrinos is measured from the ensuing Cerenkov radiation collected in an array of 10,000 photomultiplier tubes surrounding the 12-m-diameter acrylic vessel housing the heavy water. The neutral-current (NC) interaction can proceed with equal probability by all active neutrino species. The total integrated flux of neutrinos reaching the Earth is deduced upon counting the number of free neutrons liberated in the detector from the NC-disintegration of deuterium. If electron neutrinos produced in the sun's core experience flavor transitions to other active neutrino states then a ratio of the CC (electron-neutrino) flux to the NC (total-neutrino) flux will provide the "smoking gun" that neutrino oscillations are responsible for the solar neutrino deficit.

Presently in the commissioning phase, it is anticipated that the SNO detector will become fully operational in early 1999. The holy grail of SNO is a robust measurement of the CC/NC ratio. Our team has thus focused on the NC-measurement, and originated the design and development of an ultra-low background array of ^{3}He-proportional counters to be deployed throughout the heavy-water volume. In this way, the NC-signal can be measured independently but simultaneously with the CC-spectrum. Full-scale construction of an 800-m array of NC-detectors is presently underway in collaboration with our colleagues at the University of Washington.

Milagro Gamma-Ray Observatory at Fenton Hill

C. Sinnis [(505) 667-9217], T. J. Haines, C. M. Hoffman, and R. S. Miller (P-23); G. Gisler (NIS-2); and collaborators from the University of California at Irvine, the University of California at Riverside, the University of California at Santa Cruz, the University of Maryland, the University of New Hampshire, New York University, the University of Utah, and George Mason University

The Milagro Gamma-Ray Observatory is a new type of detector designed to map and study the very-high-energy (VHE) (30 GeV–30 TeV) gamma radiation in the universe. Milagro is sensitive to gamma rays with energies above ~250 GeV and is the first detector capable of continuously monitoring the entire overhead sky in this energy band. The large aperture and high duty cycle make Milagro ideally suited to study the long-term behavior of known sources of VHE gamma rays (pulsars and active galaxies), discover new sources of VHE gamma radiation, and search for "bursts" of VHE gamma radiation.

The Milagro detector is located at Fenton Hill, about 35 miles east of Los Alamos in the Jemez Mountains. The detector consists of a 6-million-gallon water reservoir, built by the Laboratory to study geothermal energy generation. The reservoir is 25-ft deep, 270-ft long, and 200-ft wide. We have installed a new liner and a light-tight cover. The cover can be inflated for installation and maintenance operations. The reservoir is instrumented with 723 photomultiplier tubes (PMTs) distributed in two layers. The top layer (450 PMTs) will be covered by 1.5 m of water, and 7 m of water will cover the bottom layer (273 PMTs). The PMTs are suspended by Kevlar string from a grid of sand-filled PVC. The grid spacing is 3 m. The PMTs detect the Cerenkov light generated by the charged particles in extensive air showers (the particle showers generated by nuclear and electromagnetic interactions as the primary cosmic rays dissipate their energy in the atmosphere). At ground level, the extensive air shower is shaped like a pancake with a diameter of 50 m and a thickness of 1 m. The pancake is oriented perpendicular to the direction of the primary cosmic ray. By measuring the arrival time of the shower over a large area, the direction of the primary cosmic ray can be determined to within about 0.7°. The event rate in Milagro will be over 1 kHz.

In the past year, we operated a prototype detector nicknamed Milagrito. With a duty factor above 85%, Milagrito recorded nearly 10 billion cosmic ray showers. While data analysis is still in progress, we have detected gamma radiation from one active galaxy (Mrk 501). The prototyping of components and investigation of the water Cerenkov technique were the most important contributions of Milagrito. We found the failure rate of the PMT bases to be unacceptably high, and new bases were manufactured and installed on all of the PMTs. Most importantly we discovered that the arrival time distribution of the Cerenkov light was much wider than expected. To solve this problem, reflective cones were manufactured and placed around every PMT.

Currently all of the PMTs and reflective cones have been installed and the reservoir is filled with 2.5 million gallons of water. The laser calibration system, cable plant, electronics, and the data acquisition system are complete. We began engineering runs in November 1998 and physics running will begin in the spring of 1999. By the end of 1999 we should produce the first-ever map of the TeV Universe.

Camera Research and Development

G. Yates [(505) 667-7529] (P-23)

Design and fabrication of two prototypes for a high-speed, intensified, shuttered, multiport CCD camera (model GY-11) were nearly completed in FY98. The intensifier/shutter component has been verified to be capable of shuttering in the 100 to 200-ps range. This design incorporates a stripline microchannel plate image intensifier (MCPII) designed at Los Alamos and manufactured by Philips Components. It is gated by injecting electrical gate pulses into a microstrip impedance-matching transmission line. The stripline design minimizes impedance variance across the MCPII to reduce gate-pulse reflections, and the microstrip design matches the 4 to 5-W impedance of the MCPII to the 50-W impedance of the gate-pulse generator. Three circuit boards designed to control, measure, encode, and recode the MCPII gain and gate variables in real-time have been completed, and preliminary testing was accomplished during the last two months of FY98. One remaining circuit board, which will allow real-time viewing of the analog video from the 16 ports of the GY-11 camera, has yet to be fabricated. The CCD component of the GY-11 camera is in test status. Images have been obtained from individual segments, and preliminary dynamic range and resolution have been characterized. The coupled system response has yet to be assessed. Auxiliary circuitry, including power supplies, control, cooling, *etc.*, are in various stages of testing.

Recording media are in the design phase, with two different designs underway: one for DOE use on subcritical experiments at NTS, and a second for Department of Defense (DOD) use in military range-gated applications for the U.S. Air Force and Army. The DOE unit will store between 2 and 10 frames, whereas the DOD unit will store 1 to 2,000 frames. Both systems will be deployed in FY99. Both the DOE subcritical experiments and the DOD range-gated experiments require infrared spectral sensitivity in the 1- to 2-μm range. We are currently looking at two different technologies to accomplish this. One is to use Intevac proprietary transferred-electron photocathodes, and the second is to use optical parametric oscillators and amplifiers for wavelength conversion. Preliminary experiments have been done on both techniques.

In addition, new packaging/housing for the image intensifiers for our proton radiography cameras is in design. The major changes are to use a metallic housing for radio-frequency shielding and for electrical safety. Commercially available high-voltage connectors have been incorporated into the new design for computer control of the intensifier gate width and gain.

Finally, the GY-11 MCPII component was used on range-gate experiments for the U.S. Army at Redstone Arsenal in July 1998 to image military vehicles through smoke screens. Images were obtained from the reflected laser beam bouncing off the vehicles stationed beyond the smoke screen, demonstrating the technique of range gating.

Infrared Pyrometry for Temperature Measurements of Shocked Free Surfaces

A. W. Obst [(505) 667-1330] and M. D. Wilke (P-23); and collaborators from Bechtel Nevada

Measurements of the time-dependent absolute temperature of surfaces shocked by high explosives provide valuable constraints on the equation of state of materials and of the ejecta from those shocked surfaces. These temperatures lie typically in the range of 0.04 to 0.2 eV, corresponding to shock heating of surfaces to temperatures from about 400°K to about 2,000°K. These temperatures are equivalent to infrared wavelengths in the range of 1 to 8 µm. Blackbody infrared spot pyrometry using the color ratio technique permits a measurement of these surface temperatures. An *a priori* knowledge of the behavior of the surface emissivity with wavelength is required, but not the absolute value of the emissivity.

First-generation pyrometers have been fielded over the last two years, both locally and at NTS. The detector system uses infrared lenses to image a spot (whose diameter is determined by the optics) onto a gold mixing rod. The mixing rod allows spatially homogenized samples of the infrared emission to be transferred to 1-mm-diameter infrared fibers (typically 3 to 7 channels). The other end of the fibers goes to a detector box, which is protected from the high-explosive shock. The infrared radiation from each fiber is focused through a doublet lens system onto HgCdZnTe infrared detectors operated at –40°C. Filters are placed between the doublets to transmit infrared radiation only from moderately narrow bands. Limited comparisons with thermographic-phosphor techniques have produced good temperature agreement on local copper flyer-plate experiments. The emissivities employed were constrained to follow the static wavelength behavior.

A second-generation pyrometer has been designed. This consists of seven InSb channels mounted in a cryogenically cooled vacuum canister operated at 77°K. Low-pressure gas in a “cryotiger” geometry makes this a very affordable option, compared to the much more expensive Sterling coolers or the unwieldy liquid nitrogen approach. Limited tests using a commercial InSb liquid nitrogen-cooled detector suggest very high detectivity, at least two orders of magnitude higher than the four-metal detectors used above. The useful wavelength range should be from below 1 µm to about 6 µm, pending the results of a newly-installed sapphire window on the test detector. Broad-range dichroic splitters coupled with narrow-range infrared filters will provide a much smaller footprint than the above mixing-rod geometry.

Large uncertainties in inferred dynamic emissivities can be addressed, for example, by the use of laser polarimetry, or ellipsometry, near one of the seven wavelength channels. This has been proposed and is being studied. Such modulated (for background mitigation) laser systems are commercially available and are being investigated. Such an ellipsometer also serves as a useful melt diagnostic, and this has also been proposed.

Dynamic Temperature and Velocity Measurements using Neutron Resonance Spectroscopy

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Neutron Resonance Spectroscopy (NRS) provides a way to measure temperatures inside dynamically-loaded systems. A successful realization of this capability will provide previously unobtainable temperature information important to the shock physics, weapons physics, and industrial communities. Our collaboration uses epithermal neutrons produced when a spallation target/moderator is struck by single LANSCE beam pulses (2×10^{13} protons) to measure temperatures on time scales ranging from tens of microseconds down to the sub-microsecond level. The development of remotely locatable neutron sources of equivalent brightness would permit the porting of the temperature measurements to other facilities such as NTS or Atlas. Temperatures are determined by accurately measuring the Doppler broadening of resonance line-shapes, which appear in the transmission spectra of neutrons passing through the sample.

To optimize the time resolution of our measurements and to maximize the neutron flux at our samples, we have developed a source target/moderator assembly (TMA) that provides a bright neutron source that can be located a factor of six times closer than is possible with the normal MLNSC source. To realize optimal benefits from the TMA, we run our experiments using single proton storage ring (PSR) beam pulses that are delivered to Target 2 at the Weapons Neutron Research (WNR) blue room. For the present flux levels at the MLNSC, static, single beam-pulse temperature determinations have been performed that demonstrate a statistical sensitivity of 30°K. We have performed measurements in dynamic systems to study temperatures in shocked metals (after the passing of the shock wave) and in the interior of an explosively-driven metal jet. Additional experiments to look at the temperatures in detonating high explosives, in the dead zones of explosives, and at the frictional interface of shocked materials are planned. We have quantitatively studied distortions to our measured resonance line shapes—distortions that result from the slowing of neutrons in the moderator, the emission of phosphorescent light in our detectors, and the presence of backgrounds in the detected signal. We are currently developing and testing new detectors with potentially reduced gamma-ray sensitivities and an absence of phosphorescence.

PLASMA PHYSICS (P-24)

Indirect-Drive ICF Experiments with Multiple Beam Cones at the Omega Laser Facility

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Indirect-drive ignition target designs for the NIF use cylindrical hohlraums with several beam cones illuminating each end of the hohlraum. Independent pulse shaping of the different beam cones will be used to reduce time-dependent flux asymmetries on the capsule. Recently, the Omega laser facility was activated at the University of Rochester's Laboratory for Laser Energetics. Designed for direct-drive inertial confinement fusion applications, the facility consists of 60 beams arranged symmetrically around a spherical target chamber. With the closing of the Nova laser facility at Livermore scheduled for mid-1999, the ability to use Omega for indirect-drive experiments has become important.

Symmetry experiments have been performed on the Omega laser facility using cylindrical hohlraum targets with as many as 40 beams arranged into multiple beam cones. These experiments constitute a first step in the development of "beam phasing," in which beams arranged in multiple beam cones form multiple rings of beam spots on the inner surface of a cylindrical hohlraum. These experiments also demonstrate the ability to model hohlraums incorporating multiple beams cones and to tune the time-integrated capsule flux asymmetry by adjustment of the beam pointing.

Studies of Convergent Hydrodynamics in Cylindrical Implosions

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Understanding hydrodynamic instability in convergent and compressible systems is important for ICF ignition and nuclear weapons research. Cylindrical implosions can provide physical insight into hydrodynamics issues because cylindrical geometry allows for excellent diagnostic access along a line of sight and simplifies modeling implosions to two dimensions. Cylindrical implosions have been performed using indirect drive the Nova laser at Livermore and using direct drive at the Omega laser at the University of Rochester. This work is discussed in detail in a research highlight in Chapter 2.

Tetrahedral-Hohlraum Design for Effectively Using the Omega Laser in Indirect Drive

K. A. Klare [(505) 667-7719] (P-24) and collaborators from P-24, X-PA, MST-7, Lawrence Livermore National Laboratory, and the University of Rochester Laboratory for Laser Energetics

The Omega laser facility at the University of Rochester provides 60 laser beams surrounding 12 pentagonal and 20 hexagonal ports. An effective use of most or all of these beams in indirect drive can be done using the tetrahedral geometry. A spherical hohlraum has four equally spaced circular laser entrance holes—connecting lines would form the edges of a regular tetrahedron. The 15 most perpendicular beams are sent into each laser entrance hole. The laser beams are focused inside the hohlraum and the diverging beams land on the sphere with spot sizes having a reasonable power for conversion to x-rays. These x-rays can implode a central spherical capsule or uniformly irradiate a portion of the sphere opposite to each laser entrance hole.

The positions of the laser beams within each hole are determined by the needs to clear the entrance hole, to clear the exit hole for six beams, and to avoid a central target capsule for six beams. The laser spots must not be too intense or too diffuse for good x-ray conversion. Special programs were written in a mathematical language (IDL) for a display program

(QD3D) to test these 3-D problems and assess the clearance of other objects like shields and backlighters. The result is a schematic display with the thin gold hohlraum and two of its near holes, which are shown as wire-frame disks, and the two far holes, which are shown as solid disks. Each laser beam is shown as input and output opaque cones with black spots where they land. A diagnostic stray-light shield in wire frame dominates one side.

High Convergence ICF Implosions in Tetrahedral Hohlraums at Omega

G. R. Bennett [(505) 667-9318], A. Hauer, and T. J. Murphy (P-24); J. M. Wallace (X-PA); and R. S. Craxton and J. D. Schnittman (University of Rochester Laboratory for Laser Energetics)

The NIF, currently under construction at Livermore, will be a 1.8-MJ, 192-beam laser facility with a mission to implode and ignite fusion burn and gain in a ~2-mm-diameter ICF capsule. The beams will be directed into each end of a cylindrical hohlraum (radiation case), such that two spatially and temporally separated laser rings per entrance hole irradiate the gold wall. Rapid thermalization of the resulting x-ray radiation will implode the ICF capsule to temperatures and mass-densities comparable to those in nuclear weapon detonations and certain classes of stars.

A possible difficulty of such an implosion is the time-dependent and time-averaged "drive" that the fuel capsule experiences. In particular, with careful beam pointing and temporal phasing of the laser cones, the NIF cylindrical hohlraum will at best achieve $P_2(\cos\theta) \equiv 0$ and a negligible $P_4(\cos\theta)$ mode, which is the nth Legendre polynomial moment, in the drive uniformity. Calculations of this hohlraum configuration indicate ignition yields may be very sensitive to beam pointing and phasing errors, implying ignition could become a rather hit-or-miss affair.

Tetrahedral hohlraums (four laser entrance holes placed on each vertex of a tetrahedral), on the other hand, exhibit zero l = 1, 2, and 5 spherical harmonic components independent of beam refraction, spot motion, *etc.* In addition, with carefully chosen pointing and temporal phasing, the l = 3 and 4 contributions can be zeroed for all times. Clearly, this inherent symmetry may have significant advantages. To this end, Plasma Physics Group (P-24) researchers are investigating high-convergence ICF implosions in such hohlraums using all 60 beams of the 30 kJ Omega laser at the University of Rochester. Our first experiment, performed in September 1998, already indicates an implosion quality comparable to a cylindrical hohlraum. With capsule design refinements during 1999, we hope to improve upon this further, and at the same time gain a better understanding of the hohlraum physics in this unique geometry.

Studies in Support of Core Science and Technology Issues for the NIF

N. A. Kurnit [(505) 667-6002] and R. F. Harrison (P-24)

Earlier studies of nonlinear optics issues of importance to the design of the NIF, such as self-focusing and Raman scattering, have been completed and replaced primarily by issues of damage and spatial filter fabrication. We have shown that it is possible to obtain very high damage thresholds by grazing incidence from a glass substrate, and tapered glass spatial filter pinholes have been fabricated and recently tested at Trident (in collaboration with S. Letzring and R. P. Johnson) based on this concept. Such pinholes show promise of providing the desired spatial filtering without causing closure for high-power glass-laser systems such as the NIF, Omega, and the proposed Trident Upgrade.

Planar, Ablative Rayleigh-Taylor Instability Experiments

G. T. Schappert [(505) 667-1294] and S. E. Caldwell (P-24); D. E. Hollowell (XTA); and R. J. Mason (XPA)

This project is a continuation of our experimental program on ablative Rayleigh-Taylor instability growth in copper foils driven by hohlraum radiation generated by the Nova laser. The purpose of our research is to experimentally explore the Rayleigh-Taylor instability in a high-density material and obtain results that can be modeled by various laboratory codes, thus benchmarking these codes with real experiments. The experimental techniques involve time-resolved x-ray radiography of a corrugated copper target as its imposed corrugations grow. The analysis of the transmission images then results in a determination of the corrugation development and the amplitudes and harmonics generated. At this point we are still in the process of resolving some differences between the experimental results and the code predictions. The experimental issues involve instrument calibrations, such as the modulation transfer function of the gated imagers. These are being investigated in the laboratory. The code issues are being addressed by X Division. The next step in the project is to investigate the classical Rayleigh-Taylor instability in corrugated copper targets by hohlraum-driving such a target with a layer of a low-Z material on top. This will generate a material pressure in addition to the ablative pressure on the copper surface. Calculations indicate a larger instability growth because of the added pressure and reduction in ablative stabilization. Since Nova will shut down in Spring 1999, these experiments are planned for the Omega laser facility at the University of Rochester's Laboratory for Laser Energetics.

Laser-Plasma Interaction Experiments in a Single Hot Spot

D. S. Montgomery [(505) 665-7994], R. P. Johnson, J. A. Cobble, and J. C. Fernández (P-24); and H. A. Rose (T-13)

Interaction experiments using realistic lasers are often difficult to interpret, even for well-defined plasma conditions, since the laser-beam intensity and phase structure are complicated. Parametric instabilities such as stimulated Raman scattering (SRS), stimulated Brillouin scattering (SBS), and self-focusing can occur to varying degrees within individual “hot spot” structures in such laser beams, and it is uncertain how instabilities produced in an ensemble of hot spots might interact with each other. This further complicates understanding of the onset and nonlinear behavior of these instabilities. These issues are still present in interpreting experiments using random-phase-plate-smoothed laser beams. Experiments studying the interaction from a single hot spot, such as from a diffraction-limited laser beam, might overcome many of these issues.

We have begun a series of experiments funded by Laboratory-Directed Research and Development (LDRD) using the Trident laser facility to study SRS, SBS, and self-focusing in a diffraction-limited (single-hot-spot) laser beam. These experiments are discussed in detail in a research highlight in Chapter 2 and summarized below. A separate heater beam is used to create a quasi-homogeneous, large-scale, hot plasma with T_e ~1 keV, L ~1 mm. Imaging self-Thomson scattering from electron-plasma and ion-acoustic waves is used to measure time-resolved spatial profiles of the electron density, electron and ion temperature, and flow velocity. A diffraction-limited beam interacts with this well-characterized plasma, and the plasma density and acoustic damping are systematically varied. The laser-intensity profile is characterized as a diffraction-limited speckle, whose width is $\sim f\lambda$, and length is $\sim 8f^2\lambda$, where f is the f-number of the focusing optic, and l is the laser wavelength. The parameters for the diffraction limited laser are λ = 527 nm, 200 psec, f/7, and the intensity can be varied between 10^{14} W/cm^2 and 10^{16} W/cm^2. The transmitted beam angular distribution is measured to indicate the activity of self focusing and beam steering in the plasma, and SRS and SBS backscattered light are also measured. Since the laser has a single, well-defined intensity, the instabilities can be studied in regimes where only one or a combination of the instabilities are active by varying the laser and plasma conditions.

Initial experimental results show evidence of beam breakup by filamentation and beam steering in these high-Mach-number, transverse-flow plasmas. We also observe SRS and SBS to be anti-correlated in time when both instabilities are present. We have used the techniques developed in these LDRD-funded experiments to enhance our experimental capabilities on larger-scale experiments. Initial experimental results have been obtained using imaging Thomson scattering to locate ion-acoustic waves associated with SBS in a large-scale plasma driven with an random-phase-plate-smoothed laser. The self-Thomson scattering technique has also been used to characterize other laser-produced plasmas on Trident.

Characterizing Saturated SBS Levels of a Realistic Speckled Laser Beam in a Fusion-Relevant Plasma at Trident

J. C. Fernández [(505) 667-6575], J. A. Cobble, D. S. Montgomery, and R. G. Watt (P-24); B. Bezzerides and S. R. Goldman (XPA); E. L. Lindman (XTA); H. A. Rose (T-13); and collaborators from Lawrence Livermore National Laboratory and the University of Nevada at Reno

There is now ample evidence that the reflectivity of laser light due to SBS from long-scale plasmas normally saturates when the laser intensity is increased sufficiently. Unfortunately, the observed saturation levels are often very high. This potentially high laser reflectivity from SBS is a concern for indirect-drive laser fusion because the efficiency of the laser drive could be seriously compromised. As a necessary first step before SBS can be controlled, we have applied a large diagnostic complement to laser-produced plasmas at the Trident laser facility to attempt to characterize the nature of this saturation. The first phase of this research has been completed and published. Our results indicate that in spite of the observed saturation of SBS with laser intensity, a significant increase in the saturated SBS reflectivity can result from increasing the fluctuation levels from which SBS grows, *i.e.*, by seeding SBS. This is done by injecting into the plasma a modest external light beam at a wavelength near that of the scattered light. This indicates that the saturation mechanism (not presently understood) is not robust and depends on the initial plasma conditions.

The next, presently ongoing, step in this research is to apply collective Thomson-scattering imaging diagnostic techniques to this system. As a result, we shall ascertain the spatial location of the SBS activity in our long-scale plasma with and without seeding the SBS. That way we can determine whether the changes in SBS amplitude are due, for example, to changes in the spatial gain rate of the instability or to excitation of SBS in plasma regions which would not otherwise support SBS without a very strong initial seed.

Laser System for Imaging Turbulence in a Gas Shock Tube

N. A. Kurnit [(505) 667-6002] and R. P. Johnson (P-24)

DX-Division personnel (R. F. Benjamin, P. Vorobieff, and P. M. Rightley) are nearing completion of assembly and testing of an illumination source for gas shock-tube studies. This source has already been demonstrated to obtain interesting and useful data on the Richtmyer-Meshkov instability. Detailed modeling of such experiments provides a stringent test of hydrodynamics codes. The 0.532-µm illumination source, assembled from largely existing components, replaces a series of leased lasers with which the earlier experiments were performed, and will provide a more accessible and versatile system for continuing experiments.

Magnetized Target Fusion

K. Schoenberg [(505) 667-1512] and F. Wysocki (P-24)

Magnatized target fusion (MTF) is a truly different approach to laboratory fusion that promises a low-cost, fast development path. MTF uses an inertial driver, in the form of a metalic liner, to compress and heat a magnetized target plasma to thermonuclear burn conditions. In 1998, a small team of Los Alamos scientists in collaboration with other laboratories and academia proposed to the DOE a proof-of-principle demonstration of MTF. Specifically, we proposed to form and pre-heat a compact torioid target plasma and then compress it to near-fusion-burn conditions with demonstrated imploding liner technology. The proposal was peer-reviewed in May 1998 by a panel of fusion experts. Based on their positive recommendations, the DOE Office of Fusion Energy Science will begin funding MTF research in FY99.

Dynamic Properties of Materials

A. Hauer [(505) 667-5643], G. Kyrala, and A. Foresman (P-24)

P-24 (in collaboration with other groups in Physics Division, X Division, DX Division, T Division, Oxford University, Edinburgh University, and the University of California at San Diego) is using the Trident laser system to pursue studies of the dynamic properties of materials that are of interest to the ICF program and to weapons science. The high-intensity pulses from the Trident laser drive shock waves varying in pressure from tens of kilobars to several megabars into condensed materials. Separate beams of the laser system can be used to create accurately synchronized, powerful x-ray and optical pulses. Using this configuration, the group has developed new diagnostic methods such as transient x-ray diffraction. This method has in turn been used to measure the dynamic properties of phase changes in materials. The methods developed on Trident are being applied to materials of central interest to ICF, such as beryllium. In addition, studies are underway to apply the methods developed on Trident to larger scale experiments on pulsed-power and explosive systems.

Equation-of-State Measurements using Laser-Driven Radiation Cavities

D. S. Montgomery [(505) 665-7994], W. W. Hsing, and A. H. Hauer (P-24); and R. Kopp (XTA)

We have evaluated the use of laser-heated radiation cavities (hohlraums) on the Trident laser facility to drive high-pressure uniform shocks in solid materials. The creation of such shocks might be used to perform high-accuracy EOS measurements. We have irradiated 1-mm-scale hohlraum targets using 4×10^{11} W laser power with two beams of the Trident laser. We have evaluated the shock conditions using time-resolved optical breakout from the free-surface of several different packages mounted on the hohlraum. Measurements of shock breakout from 27-µm-thick flat aluminum packages indicate pressure uniformity better than 1% over a 300-µm diameter. Data from wedged aluminum packages are used to infer radiation temperature and shock steadiness, and indicate a brightness temperature of 100 eV. The relative shock speed appears constant to ~1% over a thickness of 30 to 50 µm in the aluminum wedge. Finally, initial Hugoniot data have been obtained for copper using the impedance-match technique, with aluminum as the reference material. Pressures up to 4 Mbar are demonstrated in the aluminum. The data are in good agreement with current SESAME models, and with other experiments. The accuracy of the shock-speed measurement is presently ±3% and is currently limited by the metrology of the target thicknesses and by signal-to-noise in the optical breakout times. Future improvements can be expected to reduce the errors in shock speed to ~1%.

Advanced X-Ray Optics for High-Energy Density Physics

G. R. Bennett [(505) 667-9318], A. Hauer, and P. J. Walsh (P-24); and T. W. Barbee, Jr. (Lawrence Livermore National Laboratory)

The study of high-energy density regimes developed with above-ground devices often involves temporally resolved x-ray radiography of extremely small features, the scales of which can seriously limit data quality. For example, the study of very-high-pressure EOS driven by laser-produced shocks may restrict sample thicknesses such that the x-ray spatial resolution of existing instruments (along with poor signal-to-noise ratios and non-uniform x-ray backlighter sources) limits experimental EOS accuracies to approximately 10%. Poor signal-to-noise ratios are a particularly adverse trademark of present x-ray imaging techniques in both high-energy-density physics (HEDP) and ICF experiments.

To address this issue, P-24 researchers have directed attention towards significantly improving both 1-D and 2-D temporally resolved x-ray imaging quality at 5 to 25 keV or even higher. The result is a decision to use grazing-incidence-reflection focusing from multilayer-coated, spherical mirrors of the quality used on the Hubble Space Telescope Upgrade. In addition, P-24 researchers have developed (1) a novel ray-trace optimization algorithm in conjunction with analytic geometric aberration corrections for extracting maximum design performance; (2) an analytical optical-transfer function representing the statistical effects of atomic-scale surface scattering; (3) two instrument designs for the NIF laser system presently under construction at Livermore; and (4) a 1-D x-ray microscope, the 4.316-keV 1DKB, which is nearly completed for use at both the Trident laser facility at Los Alamos and the Omega laser at the University of Rochester. Rigorous analysis of the exquisitely fabricated mirrors, atomic surface statistical effects, and all other inherent defects indicates that the 1DKB instrument will provide significant spatial resolution and enormous signal-to-noise improvements for certain classes of HEDP and ICF experiments. Applying the same analysis to existing grazing-incidence instruments closely predicts their 3- to 5-µm spatial resolutions.

Physics Support for Atlas Development

B. P. Wood [(505) 665-6524], C. Munson, and G. Kyrala (P-24)

A small team has been formed to provide physics support for the design and initial operation of the Atlas pulsed-power facility. P-24 staff have contributed to this effort by examining experimental campaigns that are likely to be conducted on Atlas. The first of these deals with additional investigation of Rayleigh-Taylor mix experiments, which have been the subject of an ongoing campaign using the Pegasus facility. Other experimental configurations investigated deal with adiabatic compression of materials to extremely high pressures, EOS-measurement experiments, and conditions for the generation of strongly coupled plasma targets.

Friction Studies

G. A. Kyrala [(505) 667-7649] (P-24); J. Hammerberg (XNH); D. Oro, J. Stokes, and D. Fulton (P-22); and W. Anderson (MST-7)

We are using the Pegasus pulsed-power facility to examine the effect of dynamic friction upon sliding interfaces. We are using an aluminum liner accelerated by the Pegasus capacitor bank to launch shocks into two dissimilar materials perpendicular to their interface. The differential in shock velocity has been observed to cause a relative motion of the material parallel to the interface. By implanting opaque wires into the materials and by using x-rays to image the wires, we study how the interface moves and we also measure the distortion of the material due to this friction effect. A first shot was conducted on Pegasus and we were successful in performing the imaging. Future shots are planned, and the work will be extended to other conditions and materials.

Decontamination of Chemical and Biological Warfare Agents using an Atmospheric-Pressure Plasma Jet

G. Selwyn [(505) 665-7359] and H. Herrmann (P-24)

The atmospheric-pressure plasma jet (APPJ), a Los Alamos invention, represents a new realm of highly collisional plasma physics. A nonthermal, uniform-glow, radio-frequency plasma discharge operated at atmospheric pressure produces chemically reactive species that can be blown onto a surface. This method has been shown to kill Anthrax surrogate spores ten times faster than thermal sources, and to oxidize certain nerve gases and mustard blister-agent simulants. It offers a dry, fast, nondestructive, safe, portable, and environmentally sound method of decontamination that can be applied to sensitive equipment (electronics, optics, computers, *etc*.) and the interiors of military vehicles (planes, tanks, ships, *etc*.), which cannot tolerate harsh conventional decontamination treatments using "wet" chemistry. Military, industry, and university collaborations have been established to develop this technology, and testing on actual chemical warfare agents is proceeding at the U.S. Army's Aberdeen Proving Ground.

Plasma-Based Removal of Surface Radioactive Contamination

C. Munson [(505) 667-7509] (P-24); P. Chamberlin (retired) and J. Veilleux (CST-7); and J. R. Fitzpatrick (NMT-2)

This project focused on the development and demonstration of plasma-based techniques for the removal of surface radioactive contaminants such as plutonium and uranium that form volatiles with fluorine. Early work by Joseph C. Martz demonstrated the removal of plutonium from the surfaces of contaminated material coupons in a down-stream plasma-immersion reactor that used a mixture of CF_4 and O_2 as the plasma precursor gas. Development work during this LDRD project focused on more aggressive plasma conditions (a combination of physical sputtering and reactive ion etching), as well as much more scalable plasma generation techniques. Tests involved both prepared material coupons contaminated with depleted uranium, and a number of material samples contaminated with depleted uranium during Los Alamos experimental work. In addition, a significant investigation of contaminant removal from high-aspect-ratio crevices was performed. Because of the developmental work performed, several companies remain interested in further developments in this area.

Advanced Technology PSII Precommercialization Project

C. Munson [(505) 667-7509] and B. Wood (P-24); and K. Walter and M. Nastasi (MST-8)

This project, which is ultimately supported by the DOD/NIST Advanced Technology Program, is a follow-on to a CRADA between Los Alamos and General Motors (GM), which significantly advanced the state of the art in industrially relevant plasma source ion implantation (PSII) technology and techniques. Primary objectives of the overall program focus on driving high-risk, but potentially very high-return, fledgling technologies toward commercial application. Program participants include GM, Boeing, DuPont, Asea Brown Boveri, Litton Electron Devices, Nano Instruments, Diversified Technologies, Ionex, PVI, Empire Hard Chrome (EHC), A. O. Smith, Harley-Davidson, Kwikset, the University of Wisconsin (UW), and ERIM. Los Alamos's role in this program is to provide scientific and technical developmental support to the program participants, as well as scale-up development and demonstrations involving industrial components. Because of this program, PSII surface treatment is now available on a limited prototype basis from EHC in Chicago, and it will be available from two additional service providers (PVI and Ionex) within the next year. The success of this project earned the major program members (Los Alamos, GM, UW, EHC, and North Star Research in Albuquerque) one of *R&D Magazine*'s prestigious R&D 100 awards in 1997.

Specific research being conducted at Los Alamos includes scale-up and demonstration of the application of diamond-like carbon (DLC) coatings to industrially relevant numbers (~1,000 simultaneously) of automotive pistons; PSII surface modification of full-scale industrial dies and tooling components; development of techniques for the application of adherent DLC coatings to 400-series steel materials (a subproject with Boeing), surface engineering of manufacturing components and materials through PSII and DLC coatings (a subproject with DuPont), and application of high-hardness DLC coatings to industrial components using a cathodic arc source (another portion of the DuPont subproject).

R&D 100 Award LDRD Support of PSII Activities

C. Munson [(505) 667-7509] and B. Cluggish (P-24); and K. Walter (MST-8)

Los Alamos has established a tradition of recognizing winners of the R&D 100 award by providing one year of LDRD support for small projects related to the award. This project is one example. We focused primarily on the investigation of the plasma sheath dynamics involved in PSII of very large, complex targets.

In order to successfully commercialize PSII techniques, it is necessary to maximize the number of components that may be treated simultaneously in a given facility. This requires an understanding of the complex interactions between the 3-D assembly of target components and the initial plasma generated around this assembly, as well as the interactions between the target surfaces, the background plasma and neutral gas, and the plasma sheaths, which dynamically evolve during the PSII process. Since the energies involved in the PSII process are so large (tens of keV) compared to the energies of the background plasma (~eV), and energetic secondary electrons are generated by ions impacting the target surfaces, significant energy is available for the potential development of instabilities in the plasma during the plasma sheath evolution. Langmuir probe measurements within a target assembly during PSII have been used to characterize the dynamic sheath conditions, and to identify two instabilities driven by the complex interactions present. This work is described in detail in a research highlight in Chapter 2.

Characterization of Dipole Interactions in Dusty Plasmas

H. R. Snyder [(505) 665-8364] and G. S. Selwyn (P-24); and M. S. Murillo and D. Winske (XPA)

We constructed a radio-frequency plasma chamber incorporating an electrostatic trap for studying various properties of dusty plasmas. Our plasma system is capacitively coupled with an asymmetrical electrode geometry. We introduce well-characterized glass microspheres of various diameters (1.0 to 50 µm) into the trap to simulate dust grains and measure properties of the dust using laser light scattering techniques in conjunction with a digitizing video capture system. In particular, we observe a crystalline phase in which the microspheres form strings aligned with the electric field, and we measure the intergrain spacing. This alignment, which has been observed in other experiments, appears to be a ubiquitous property of dust in radio-frequency plasma chambers. Because the strings behave fairly independently, it has been suggested that the dust has an acquired dipole moment. Such an interaction qualitatively describes vertical alignment of dust within a string and horizontal repulsion between strings. We have developed several estimates for the dipole strength based on nonuniform charging and ion focusing to compare with the suggested mechanism of induced dipoles within the dust. A simple theory has been developed that predicts the lattice spacing for various dipole mechanisms.

Wear- and Corrosion-Resistant Coatings for Gun Barrels

B. P. Wood [(505) 665-6524], B. Cluggish, A. Mytnikov, and D. Pesenson (P-24); and M. Hakovirta (MST-8)

The goal of this work is to demonstrate a process for producing adherent refractory metal coatings for wear and corrosion resistance on the insides of large-caliber (120-mm) gun barrels. Work in FY98 has centered around understanding the physics of drifting, cathodic-arc-produced plasmas in magnetized, biased pipes. Two papers describing this work have been published in *IEEE Transactions on Plasma Science*. Implantation on the inside surfaces of pipes was achieved by biasing the pipe to voltages of less than 5 kV; however, high negative voltages (greater than 10 kV) were mostly unsuccessful due to electrical arcing through the plasma. Ongoing experiments are being conducted to determine an efficient magnetic cusp design for turning an axial plasma flow into radial plasma flow impinging on the pipe walls.

High-Average-Power, Intense Ion Beam for Material Properties and Other Applications

B. P. Wood [(505) 665-6524], L. Bitteker, and W. J. Waganaar (P-24)

We are developing a repetitive, intense ion-beam source that uses a magnetically insulated diode with an active plasma anode. This source will produce a 250-kV, 12-kA, 1-μs pulsed beam of any gaseous species of ion. Applications include materials surface treatment by rapid melt and resolidification; high-rate coating production; a diagnostic neutral beam for the next generation of tokamak; and a portable, intense, pulsed-neutron source for neutron radiography, neutron resonance spectroscopy, and criticality measurements. During FY98 (the final year of this three-year LDRD project) we completed construction of the plasma anode, and characterized its operation in hydrogen and argon, both with and without magnetic insulation. Numerical modeling of gas flow through the anode nozzle suggested changes in operating pressure which were successfully adopted, and changes in plenum volume which may be incorporated in the future. Most accelerator components were fabricated, and low-voltage testing of the accelerator was in progress by the end of FY98. We have obtained funding in FY99 to complete the system and pursue pulsed-neutron-source applications.

Production of Superior DLC Coatings for Tribological Applications

B. P. Wood [(505) 665-6524] and D. Pesenson (P-24); and M. Hakovirta (MST-8)

We are investigating the production of superior DLC coatings by cathodic-arc for tribological applications. An important aspect of this research is the design of efficient magnetic ducts for filtering solid particles from the plasma stream used to create the coatings. DLC coatings have been produced with hardnesses as high as 77 GPa—higher than any reported in the literature. Initial production-line tests of industrial parts coated with this and similar processes have been encouraging. A dual cathodic arc has been constructed which will allow production of nano-layered DLC-metal composites.

Generation of 1.54-μm Radiation for an Eye-Safe Laser Lidar

N. A. Kurnit [(505) 667-6002] and R. F. Harrison (P-24); and R. R. Karl, Jr., J. P. Brucker, J. Busse, W. K. Grace, W. Baird, and O. G. Peterson (CST-1)

An existing helicopter-mounted 1.06-μm laser lidar system was modified to produce pulse energies of up to 250 mJ at the “eye-safe” wavelength of 1.54 μm by means of Raman scattering of the Nd:YAG radiation in methane. Although this had been demonstrated a number of times before, we believe this is the highest energy to be demonstrated by Raman scattering at this wavelength. This was accomplished by using a folded multipass geometry without focusing in the Raman cell so as to avoid breakdown of the methane that can lead to soot formation, as well as avoiding the generation of higher Stokes and anti-Stokes radiation that can limit the amount of energy converted to the desired first Stokes. The folding mirrors allowed a long path to be compressed into a space that was compatible with the helicopter requirements, and they were also coated to suppress the buildup of second-Stokes radiation. This system was successfully flight-tested by Chemical Science and Technology (CST) Division and Army personnel, and it produced over 2 W of average power in a series of flights measuring returns from simulants of chemical and biological weapons agents. Eye-safe 1.54-µm radiation is useful in such tests because the downward-looking nature of the system allows testing without concern for the safety of ground personnel.

MIT Alcator C-Mod Tokamak Collaboration

R. Maqueda [(505) 667-9316] (P-24)

In FY97–98, we designed, fabricated, installed, and operated an infrared viewing system to look at heating on the armor tiles of the tokamak wall and divertor regions of the Alcator C-Mod tokamak. The Alcator C-Mod tokamak is a compact, high-magnetic-field tokamak with very limited diagnostic access. We had to develop a 5-m infrared periscope that is sensitive to surface temperatures above 30°C while giving as broad a field of view as possible of the inner wall and still allowing us to position a sensitive infrared video camera outside of most of the magnetic and nuclear radiation fields around the machine. First data has been obtained, and after careful calibrations, this viewing system has allowed us to monitor the temperature rises on the molybdenum armor tiles during plasma operation.

Columbia University HBT-EP Tokamak Collaboration

Glen Wurden [(505) 667-5633] (P-24)

We built a 1-MW ion cyclotron radio frequency oscillator unit for the HBT-EP tokamak to allow beta-limit experiments to be conducted while studying MHD modes and their control by active means. The oscillator unit will be coupled through a Los Alamos-supplied transmission line and matching box to a Princeton University-supplied ion cyclotron radio frequency antenna. The equipment will be used for the first time in New York in FY99. Up to four Los Alamos undergraduate students learned about high-power electronics while working on the project, and were key to getting the project done within budget ($100k) during FY98. During FY97, we collaborated at Columbia University using two Los Alamos-built high-power (10-MW each), wide-band (0–30 kHz) amplifiers for stabilization of internal plasma modes in the same HBT-EP tokamak.

International Thermonuclear Experimental Reactor Diagnostic Reports

C. W. Barnes [(505) 665-5687], B. P. Wood, and G. Wurden (P-24)

Los Alamos has continued to lead the U.S. home-team design effort in fusion product diagnostics for the International Thermonuclear Experimental Reactor (ITER). In addition to coordinating effort on other systems, detailed design was done and documented on the neutron-activation and the neutron-source-strength monitor systems as part of completion of the ITER engineering design activity. We also wrote a section of the ITER Diagnostic Design Description for bolometry, describing the backup design for bolometers using our new infrared imaging bolometry idea for a radiation-hard system.

As part of an ITER research and development effort, we developed an intense, pulsed, diagnostic-neutral beam; characterized the active plasma anode source of the CHAMP intense ion beam; and established electric and magnetic fields, plasma velocity (about 2.7 cm/µs), and proper operation with the electron-insulating magnetic field. The main pulse of plasma is produced by the second half-cycle of ringing current through the anode fast-coil, with some additional plasma (about 10 times less) produced on the third half-cycle.

Imaging Bolometer Development for Long-Pulse Fusion Experiments

Glen Wurden [(505) 667-5633] (P-24)

The concept of a new type of bolometer that is able to image the radiation emitted by a plasma with unprecedented spatial resolution was developed and prototyped in FY97–98. A digital infrared camera is used to measure the temperature of a special segmented foil/mask, which converts the broad-band plasma radiation to heat. As part of a U.S.-Japan collaboration, and also a funds-in-agreement, we fabricated a prototype and shipped it to the National Institute for Fusion Science in Tokyo, Japan. There, we tested the concept on the Compact Helical Stellarator (CHS) while looking at 200 to 400 kW of plasma radiation produced by electron cyclotron and neutral beam heating. Los Alamos also filed U.S. Patent papers on the idea, although our prior publications ruled out any international patent rights. The U.S. Patent is pending. Two invited talks and papers were presented on the topic at both an international ITER diagnostics workshop in Varenna, Italy, and at the High Temperature Diagnostics conference in Princeton.

SUBATOMIC PHYSICS (P-25)

MEGA

M. D. Cooper [(505)667-2929] (P-25) and collaborators from P-25, NIS-6, NIS-8, DX-5, LANSCE-6, ESA-DE, the University of Chicago, Fermilab, the University of Houston, Indiana University, Texas A&M University, Valparaiso University, the University of Virginia, Virginia Polytechnic Institute, and Virginia State University

The apparent conservation of muon number remains a central problem of weak interaction physics. Searching for processes that violate muon number conservation will give insight into the possible extensions of the minimal standard model of weak interactions. An experiment called MEGA (an acronym for "muon decays into an electron and a gamma ray") was designed to make such a search at the Los Alamos Meson Physics Facility (LAMPF), now known as LANSCE. The final year of data taking for this experiment was 1995. The combined data from the summers of 1993–1995 should yield a statistical precision that improves the current world sensitivity to this process by a factor of 25 to roughly 3×10^{-12}. We have extracted the kinematic properties for all possible candidates, and we are carefully scrutinizing the final sample of about 5,000 events. We are currently in the final stages of extracting a result from the data.

RHO

R. E. Mischke [(505)667-6814] (P-25) and collaborators from P-25, NIS-6, NIS-8, DX-5, LANSCE-6, ESA-DE, the University of Chicago, Fermilab, the University of Houston, Indiana University, Texas A&M University, Valparaiso University, the University of Virginia, Virginia Polytechnic Institute, and Virginia State University

The MEGA positron spectrometer was used to measure the Michel parameter rho (ρ). This parameter governs the shape of the polarization-independent part of the energy spectrum for positrons emitted in normal muon decay. The standard model predicts ρ to be 0.75; it is currently known to be within 0.3% agreement with that value. Deviations from 0.75 might indicate the need for right-handed currents in the standard model. The energy spectrum for over 2×10^8 positrons was recorded and data were taken under several conditions to help with the analysis of systematic errors. Despite these precautions, energy-dependent systematic errors will limit the accuracy of the result to a level that is currently being evaluated.

The Phenix Detector at RHIC

J. M. Moss [(505)667-1029], V. Armijo, M. Bennett, J. G. Boissevain, M. Brooks, T. A. Carey, D. J. Clark, G. W. Hart, D. M. Lee, M. J. Leitch, L. J. Marek, P. L. McGaughey, M. M. Murray, P. E. Reimer, J. E. Simon-Gillo, W. E. Sondheim, J. P. Sullivan, and H. W. van Hecke (P-25); and W. W. Kinnison (PDO) for the Phenix collaboration

Big Bang cosmology pictures a time very early in the evolution of the universe when the density of quarks and gluons was so large that confinement inside hadrons (neutrons, protons, pions, and related particles) had no meaning. With the commencement of operations in 1999 of the reletivistic heavy-ion collider (RHIC) at Brookhaven National Laboratory, it should become possible to create a small sample of that primordial quark-gluon plasma in the laboratory and to study its exotic properties. The challenge facing the international collaborations involved in the RHIC program is to find signatures of the fleeting transition into the this deconfined phase of matter. The Phenix collaboration currently consists of over 400 physicists and engineers from universities and laboratories in the U.S. and nine foreign countries. The Physics Division, with a long history of experiments at the energy frontier, is playing a major role in defining the physics program for RHIC and in constructing two major subsystems—the multiplicity/vertex detector (MVD) and the muon subsystem—for the Phenix detector, one of two major collider detectors at the RHIC facility.

The MVD is the smallest and among the most technically advanced of the Phenix systems. It will be located very close to the region where the two beams of 100-GeV/nucleon ions intersect. Its function, as the name implies, is to give the precise location of the interaction vertex and to determine the global distribution and intensity of secondary charged-particle production, a crucial parameter in fixing the energy density achieved in the collision fireball. Although these functions are crucial to the entire Phenix physics program, the MVD must satisfy an additional exacting requirement of having little mass and being almost invisible to the passage electromagnetic radiation. Thus the 28,000 channels of silicon-strip detectors (in a hexagonal cylinder along the beam direction) and 6,000 channels of silicon-pad (in two endcaps), along with their electronics, cabling, and cooling equipment, will weigh only about 11 kg. The MVD will present less than 1% of a radiation length to the Phenix electron detectors, which view the interaction region through the MVD. This project is centered at Los Alamos but involves significant collaboration with universities in the U.S. and Korea. Much of the state-of-the-art electrical engineering of the MVD system is provided by NIS-4 and by Oak Ridge National Laboratory. The exacting schedule toward first physics operation of RHIC requires that the MVD be operational in the center of the Phenix detector in October 1999.

The muon subsystem, the largest of the Phenix subsystems, consists of two large conical magnets and associated position-sensitive tracking chambers at opposite ends of the detector. Muon identification is accomplished by recording muon penetration of a series of large steel plates interspersed with detection planes, all of which follow the magnets at each end of the detector. The muon subsystem plays a central role in the Subatomic Physics Group's (P-25's) physics agenda at RHIC. It is optimized for examining experimental observables in a kinematic regime that can be guided by the predictions of perturbative quantum chromodynamics (QCD). The muon subsystem is also a crucial element in the other major physics program at RHIC: elucidation of the spin structure of the nucleon via the collision of high-energy polarized protons. The muon capability has been on the Physics Division's agenda from the beginning of the RHIC detector collaborations. Its realization as a funded construction project follows many years of strong advocacy by Division personnel within the Phenix collaboration. A key milestone was achieved in 1995 when a working group of physicists from P-25 and the

Institute of Chemical and Physical Research (RIKEN) in Japan secured sufficient funding to complete the entire muon subsystem. The construction of the muon subsystem, although administratively centered at Los Alamos, is truly a world-wide effort. The muon tracking effort is led by Los Alamos and is largely carried out at P-25's facilities. During the past year, a major milestone was achieved in the construction and successful operation of the world's largest cathode-strip readout tracking chamber, which measures 2×3 m. This prototype is one of eight chambers that form a plane in the largest of the three tracking stations in each of the two muon magnets. When completed, each muon magnet will contain a complex of three tracking stations with a total electronic channel count in excess of 40,000. An important step in the muon subsystem construction project during the coming year is the commissioning of a factory at Brookhaven where mass production, testing, and assembly of components will be carried out. The current plan is to have one of the two muon arms instrumented for physics data collection during the first year of RHIC operation (late 1999 to 2000), with the other arm completed a year later.

High-Energy Nuclear Physics

M. J. Leitch [(505)667-5481] (P-25) and collaborators from P-25, NIS-6, Abilene Christian University, Argonne National Laboratory, Fermilab, Georgia State University, Illinois Institute of Technology, Louisiana State University, New Mexico State University, Oak Ridge National Laboratory, Texas A&M University, and Valparaiso University

We are leading a research program centered at Fermilab that has studied parton distributions in nucleons and in nuclei and the nuclear modification of QCD processes such as J/ψ production. This program began in 1987 with measurements of the Drell-Yan process in fixed-target p-A collisions, which showed that the antiquark sea of the nucleon was largely unchanged in a heavy nucleus. In our most recent measurements we also showed that there is a large asymmetry between down and up antiquarks. The latter is presumably due to the nucleon's pion cloud. In addition we showed that the production of heavy vector mesons such as the J/ψ was strongly suppressed in heavy nuclei and mapped out this effect over broad ranges. Although the causes of this suppression are not yet fully understood, it is already clear that absorption in the final state plays an important role, as do energy-loss of the partons and shadowing of the gluon distributions.

These physics interests have also led us to become involved in the RHIC program, where we are part of the PHENIX collaboration. At PHENIX we intend to pursue similar measurements of p+p and p+A collisions to study the modification of parton structure functions and QCD processes in nuclei at RHIC's larger center-of-mass energy. We will also study kinematic regions that can be reached in a collider detector like PHENIX but were not accessible in Fermilab fixed-target measurements. The PHENIX muon detectors were conceived in large part as a result of our interest in pursuing muon measurements, and the PHENIX spin program was begun when we convinced several Japanese groups led by RIKEN to join PHENIX to study spin aspects of parton structure functions.

The expertise that we already have in understanding nuclear effects on parton structure and QCD processes and the new measurements that we plan to make at PHENIX will be critical in understanding these effects in nucleus-nucleus collisions. Only after these phenomena are well understood will we be able to determine whether a quark-gluon plasma is made in heavy-nuclei collisions.

In addition we are considering further work at Fermilab to extend our measurements of the asymmetry between up and down antiquarks in the nucleon sea to larger values of antiquark momentum fraction. Such extensions will be critical in determining what the correct nonperturbative model is for this asymmetry. A letter of intent for this extension to our recent measurements has been submitted to Fermilab with Don Geesaman at Argonne taking the lead. We plan to participate in this program at a level that agrees with our effort at PHENIX.

NA44 Relativistic Heavy Ion Experiment

J. Sullivan [(505) 665-5963] (P-25)

Experiment NA44 at the European Center for Nuclear Research (CERN) is a relativistic heavy-ion experiment that searches for evidence that quarks and gluons are deconfined in matter at very high energy density. The experiment focuses on correlations among identical particles as a function of transverse momentum to provide a closer look at the space-time extent of the central region of heavy-ion collisions. A long lifetime of matter in the central region is an indication of the formation of deconfined quarks and gluons. Among the heavy-ion experiments at CERN, NA44 is unique in its ability to compare correlations of identified pions, kaons, and protons. Comparison of pion and kaon results clarifies the effects of resonance decays versus the time evolution of the emitting source. In 1996 the experiment took data for the last time. However, the analysis of the data is still in progress. In the last year, NA44 results were published that showed that the size of the region that emits pions grows as a function of the total charged particle multiplicity in S+Pb collisions. We also published the first results of pion correlations from Pb+Pb collisions at 158 GeV per nucleon. We expect all analysis to be complete within one year.

Hypernuclei Physics

J.-C. Peng [(505)667-9431], C. Riedel, and C. Morris (P-25); J. O'Donnell (P-23); and collaborators from Arizona State University, Brookhaven National Laboratory, the University of Colorado, Hampton University, the University of Houston, the University of Kentucky, Louisiana Technical University, the University of Minnesota, the University of Zagreb, and Tohoku University

We proposed Experiment 907 (E907) at Brookhaven's Alternating-Gradient Synchrotron (AGS) to study the feasibility of using the (K^-, π^0) reaction as a novel tool to produce lambda (λ)-hypernuclei with energy resolutions significantly better than the existing (K^-, π^-) and (π^+, K^+) experiments. This experiment is also capable of measuring the π^0 weak-decay modes of λ-hypernuclei never studied before. The LANSCE neutral meson spectrometer and associated equipment were moved to the AGS for this experiment. A new data acquistion system and a new array of active target chambers were also successfully implemented for E907.

During 1997–1998, E907 received approximately three months of beam. Preliminary results show that an energy resolution of 1.5 MeV has been achieved. This resolution is a factor of two better than any previous hypernuclear experiments. Measurements on a carbon target have provided the first hypernuclear spectrum using the (K, π^0) reaction. In addition, the π^0 energy spectrum resulting from the weak-decay of light λ-hypernuclei has also been measured. We are currently analyzing the 1998 data. Preliminary results from E907 have already been presented at several conferences.

Liquid Scintillator Neutrino Detector

W. C. Louis [(505)667-6723] (P-25) and collaborators from P-25, LANSCE-7, the University of California at Riverside, the University of Cincinnati, Columbia University, Embry-Riddle Aeronautical Univeristy, Fermilab, Louisiana State University, Louisiana Tech University, the University of Michigan, and Princeton University

The liquid scintillator neutrino detector (LSND) experiment at LANSCE has obtained evidence for neutrino oscillations by observing an excess of events in both the $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ and $\nu_\mu \rightarrow \nu_e$ appearance channels. These two channels are independent of each other and together provide strong evidence for neutrino oscillations in the $\Delta(\mathrm{m}^2) > 0.2\ \mathrm{eV}^2$ region. The LSND results imply that at least one of the neutrino states has a mass greater than 0.4 eV, and therefore that neutrinos contribute more than 1% to the mass density of the universe. In addition to the significance of these results to cosmological models, the existence of neutrino oscillations has great significance for nuclear and particle physics because they imply that lepton number is not conserved and that there is mixing among the lepton families. The LSND experiment, which had its last run in 1998, has also made precision measurements of neutrino-Carbon and neutrino-electron scattering.

Booster Neutrino Experiment

W. C. Louis [(505)667-6723] (P-25) and collaborators from P-25, LANSCE-7, the University of California at Riverside, the University of California at San Diego, the University of California at Santa Barbara, Embry-Riddle Aeronautical Univeristy, Louisiana State University, Louisiana Tech University, Southern University, and Temple University

The proposed booster neutrino experiment (BooNE) recently obtained approval at Fermilab to make a definitive test of the LSND neutrino oscillation results. The BooNE detector will consist of a 12-m-diameter sphere filled with 770 tons of mineral oil and covered on the inside by the 1,220 phototubes from LSND. The detector will be located 500 m away from the neutrino source, which will be fed by the 8-GeV proton booster. After one year of running, BooNE will observe approximately 1,000 $\nu_\mu \rightarrow \nu_e$ oscillation events if the LSND results are indeed due to neutrino oscillations. Furthermore, if oscillations are observed, BooNE will be able to make precision measurements of the oscillation parameters and to test for charge-conjugation-parity violation in the lepton sector. The BooNE detector should be operational by the end of 2001, and first results are expected a year later.

Electric Dipole Moment of the Neutron

M. D. Cooper [(505)667-2929] (P-25) and collaborators from P-25, P-21, P-23, LANSCE-DO, the University of California at Berkeley, California Institute of Technology, Harvard University, Institut Laue-Langevin, the University of Michigan, the University of New Mexico, the National Institute of Standards and Technology, Simon Fraser University, and the University of Sussex

An opportunity exists at Los Alamos to improve the limit on the electric dipole moment (EDM) of the neutron by more than two orders of magnitude to 4×10^{28} e*cm. The continuing reason for interest in the EDM stems from the observation of violation of time-reversal invariance in the neutral kaon (K^0) system. Many theories have been developed to explain the kaon problem, but most have been ruled out by their prediction of a sizable EDM for the neutron. Today, new classes of highly popular models (*e.g.*, supersymmetry) predict values for the EDM that are within the potential reach of experiment. In addition, if the observed baryon-antibaryon constitution of the universe is due to time-reversal-violating symmetry breaking at the electroweak scale, the range of predicted values for the EDM is also measurable.

The proposed experiment draws heavily on the ideas described by R. Golub and S. Lamoreaux [*Physics Reports* 236, 1 (1994)]. Ultracold neutrons (UCN) will be produced via the superthermal mechanism in a dilute mixture of ^{3}He in superfluid ^{4}He. The increased sensitivity arises from (1) an increased electric field allowed by the excellent dielectric properties of superfluid ^{4}He, (2) a dramatic increase in the number of UCN resulting from the production mechanism, and (3) an increased storage time due to the low temperature of the walls. Current work on the project is centered around experimental verification of the feasibility of the experiment, which is needed before a proposal can be submitted.

Ultracold Neutrons

C. Morris [(505)667-5652] (P-25) and collaborators from P-25, P-23, LANSCE-DO, the Hahn Meitner Institute in Berlin, Institute Laue-Langevin in Genoble, Princeton University, the University of California at Berkley, the University of Washington, and California Institute of Technology

Solid deuterium converters have been proposed as a source of UCN for some time. Recently it has become clear that coupling a solid deuterium moderator to the high densities of cold neutrons available from a pulsed-spallation neutron source may provide a UCN source with several orders of magnitude higher neutron density than is possible from reactor driven sources such as the Institute Laue-Langevin.

Two experiments were mounted this year to attempt to verify these predictions. In the first, UCN production from a solid deuterium converter was measured in a cold beam line at the HMI reactor in Berlin. The production rates were found to be in agreement with predictions.

Based on this result an experiment has been mounted at LANSCE to measure the UCN production rates and lifetimes from a 1-L volume of solid deuterium coupled to a spallation source on the proton radiography beam line at LANSCE. These tests are currently underway. Although the initial runs gave UCN rates roughly two orders of magnitude lower than predicted, the measured rates were large enough to provide a world class UCN source. Several problems with the initial experiment, which may explain the observed rates, have been isolated and are being remedied for future runs.

Fundamental Symmetry Measurements with Trapped Atoms

D. Tupa [(505)665-1820] (P-25); S. G. Crane, R. Guckert, M. J. Smith, D. J. Vieira, and X. Zhao (CST-11); S. J. Brice, A. Goldschmidt, A. Hime, and S. K. Lamoreaux (P-23)

With the advent of optical and magnetic traps for neutral atoms, a new generation of fundamental symmetry experiments has arisen that would exploit point-like, massless samples of essentially fully polarized nuclei. At Los Alamos we are pursuing a measurement of the beta-spin correlation function in the beta decay of rubidium-82 confined to a time orbiting potential (TOP) magnetic trap as a means to probe the origin of parity violation in the weak interaction. A new generation of atomic-parity nonconservation experiments that test the neutral current part of the weak interaction is also envisioned, wherein measurements with a series of radioactive isotopes of cesium and/or francium could eliminate atomic structure uncertainties that presently limit the ultimate precision of such experiments.

Our near-term goal is to demonstrate the high-efficiency optical trapping of rubidium and cesium radioisotopes, to polarize and transfer these cold atoms to a pure magnetic trap that confines only one polarized state, and then to measure the beta-asymmetry using a symmetric array of beta-telescopes surrounding the trap. Initial trapping and cooling of rubidium and cesium isotopes have been carried out, and we are now working to complete the design of the transfer and the second magnetic trap, where rubidium-82 atoms will be polarized and placed in a magnetic TOP trap for high-precision beta-asymmetry measurements. Our initial studies will concentrate on the pure Gamow-Teller transition in rubidium-82; our goal is to measure the parity-violating beta-spin asymmetry correlation with a precision one order of magnitude greater than any previous experiment.

Quantum Computation using Cold, Trapped Ions

D. Tupa [(505)665-1820], M. Gulley, and V. Sandberg (P-25); R. J. Hughes, M. H. Holzscheiter, P. G. Kwiat, S. K. Lamoreaux, C. G. Peterson, and C. Simmons (P-23); and M. Schauer (P-24)

Quantum computation is a new computational paradigm that is much more powerful than classical computation because it allows for computing with quantum-mechanical superpositions of many numbers at once. In a quantum computer, binary numbers will be represented by quantum-mechanical states (“qubits”). We are developing a quantum-computational device in which the qubits will be two electronic states of calcium ions that have been cooled with a laser to rest in an ion trap. We will then perform quantum logical operations with a laser beam that is resonant with the qubit transition frequency and is directed at individual ions. We have recently succeeded in trapping and imaging a cloud of calcium ions using two titanium-sapphire lasers: one frequency doubled to 397 nm, and the other to 866 nm.

Proton Radiography

C. Morris [(505)667-5652], J. F. Amann, J. G. Boissevain, C. J. Espinoza, J. Gomez, G. W. Hart, G. E. Hogan, H. A. Thiessen, H.-J. Ziock, and J. D. Zumbro (P-25); J. B. McClelland (P-DO); and collaborators from P-23, DX Division, LANSCE, T Division, X Division, ESA Division, Lawrence Livermore National Laboratory, Lawrence Berkeley National Laboratory, Brookhaven National Laboratory, the Indiana University Cyclotron Facility, and Bechtel

There are two goals for the proton radiography program. The first is to demonstrate that high energy proton radiography is a suitable technology for meeting the goals established for the advanced radiography program, and the second is to develop the capabilities of 800-MeV proton radiography for meeting immediate programmatic needs. These goals are highly coupled since most of the techniques developed for 800-MeV radiography can be used at higher energies. Most of the effort in the last year was focused on the 800-MeV program because of funding restrictions that limited progress in our planned 25-GeV demonstration at Brookhaven's AGS.

This year, a three lens system has been constructed and tested in Line C at LANSCE. This system has been used to demonstrate the utility of an upstream focus for dynamic alignment, background measurements, and beam tayloring, including graded collimation. Material identification has been demonstrated using both step wedges and other static objects with the downstream lenses. Finally, a camera system capable of recording seven time-frames has been developed and used in a number of dynamic experiments aimed at studying the temperature and lot-dependence of corner turning in insensitive high explosives. Our proton radiography work is described in detail in a research highlight in Chapter 2.

Carbon Management and Mineral Sequestration of CO_2

H.-J. Ziock [(505)667-7265] (P-25)

Today, the world energy use is dominated by fossil fuels, which account for between 80 and 85% of the total. The reasons for this include their abundant supply, high energy-density, acceptance by the public, ease of use, ease of storage, existing infrastructure, and most importantly their low cost. The only thing that presently threatens their continued widespread use is the possible environmental consequence of the vast amounts of CO_2, a greenhouse gas, released into the atmosphere as a result of their combustion. Without question, the use of fossil energy has raised the level of CO_2 in the atmosphere by roughly 30%. This change far exceeds natural fluctuations during the last few thousand years. Since 1800, the CO_2 content of the atmosphere has risen from a stable level of 280 ppm to about 365 ppm today. Nevertheless, the virtues of fossil fuels, their dominance of the market place, and the continued rapid growth in world energy demand will guarantee a continued important role for fossil energy throughout the next century. Mitigation of these CO_2 emissions is becoming an important global issue as CO_2 emissions are accelerating rapidly, and the emissions can easily reach 10 times current levels in the next 50 years due to a combination of population growth and an improved standard of living throughout the world.

Our proposed solution to this problem is to react CO_2 with common mineral silicates to form carbonates like magnesite or calcite, a reaction which is exothermic and thermodynamically favored under ambient conditions. The reaction is well known to geologists because it occurs spontaneously on geological time scales. The main advantages of the mineral carbonation method are (1) it is a natural process that is known to produce environmentally safe and stable material; (2) raw materials for binding the CO_2 exist in vast quantities, far exceeding even the most optimistic estimates of fossil energy reserves; (3) a single mineral carbonation plant could operate on the scale of emissions from several to tens of large power plants; (4) the production of mineral carbonates insures a permanent fix rather than storage of the CO_2, thereby guaranteeing no legacy issues for future generations; (5) the process favors integration into future power plants as well as application to existing power plants; and (6) implementation of the process has the potential to be economic and to produce additional value-added products.

We recently received approval of our five-year direct-research LDRD proposal titled "Cradle to Grave Carbon Management." We have identified two primary areas to be addressed. The first is the production of an alternate energy carrier, hydrogen, from fossil fuel, while simultaneously forming a pure CO_2 exhaust stream. The second is the subsequent disposal of the CO_2 through mineral sequestration. The hydrogen production will involve two different techniques. One reacts coal with water and calcium oxide, using the energy released in the carbonation reaction of calcium oxide to supply the energy needed to drive the shift reaction on water to yield hydrogen while simultaneously capturing the CO_2. The CO_2 would then be re-released at high pressure for use in the subsequent sequestration process by heating the calcium carbonate to high temperatures. This step would also yield calcium oxide, which would be recycled. The second technique would work on natural gas and would involve the use of short-contact-time catalysis reactors to generate hydrogen and CO_2. Those gases would then be separated using hydrogen separation membranes. The mineral sequestration area would also investigate two possible approaches. One would rely on an above-ground industrial process, and the second would investigate injection of supercritical CO_2 into appropriate underground strata.

Theory

M. B. Johnson [(505)667-6942] and D. Ahluwalia (P-25); J. D. Bowman (P-23); and collaborators from institutions in the Unites States, Canada, France, Israel, Kazakhstan, Russia, and Taiwan

The theory component of P-25 consists of a staff member and a number of short- and medium-term visitors from universities and laboratories throughout the world. Theoretical research focuses on basic issues of strong, electromagnetic, and weak interactions topics that complement the present activity of the experimental program and that impact possible future scientific directions in the group. As such, the theoretical component of P-25 facilitates interaction between experimental and theoretical activities in the nuclear and particle physics community and contributes to a balanced scientific atmosphere within the group.

Recent theoretical activity has focused on neutrino interactions and masses, parity violation in chaotic nuclei, deep inelastic scattering, hadron properties in free-space and in nuclei, and QCD at finite temperatures.

Education and Outreach

A. P. T. Palounek [(505) 665-2574], J. F. Amann, and H. van Hecke (P-25)

P-25 group members continue to be active in education and outreach activities, both as participants in programs sponsored by the Laboratory, and as individual citizens who volunteer their time for various activities. In the recent past, group members have acted as judges for the New Mexico Supercomputing Challenge, consulted for the TOPS (Teacher Opportunities to Promote Science) Program, participated in career days and college days at New Mexico schools, and visited nearby classrooms regularly. We also coordinated, organized, and participated in the Teacher's Day at the annual meeting of the American Physical Society's Division of Nuclear Physics.

The Group sponsors several high school, undergraduate, and graduate students to work on our projects. These students study computing, engineering, and electromechanical technical support as well as physics. A few students are writing theses based on the work they do at P-25.

PHYSICS DIVISION OFFICE

Scaling Considerations for Global Weather Sensors

G. Canavan [(505) 667-3104] (PDO); and J. Moses and R. C. Smith (P-21)

Long-range weather predictions have great scientific and economic potential, but require global observations. Small constant-pressure balloon "transponders" could serve as Lagrangian trace particles to measure the vector wind, temperature, and water vapor, which are the primary initial conditions for long-term numerical forecasts. The wind field, which is the most important factor, is difficult to measure and is poorly sampled at present. We are exploring the use of distance-measuring-equipment (DME) triangulation of signals from roughly one million transponders to sample the wind field with sufficient accuracy for two-week forecasts.

DME uses small, low-power transmitters on each transponder to produce intermittent transmissions that are detected by several small receivers and forwarded to the ground station to process the position, velocity, and state information. Thus, each transponder consists of a balloon with a small radio, and each should only weigh a few grams and cost a few dollars. Satellites used for readout should weigh a few kilograms and cost around $1M. If the receivers can be carried on high-altitude balloons, the cost per receiver might be reduced by one to two orders of magnitude. The number of transponders required depends only on the spatial resolution required, and the number of receivers depends only on the altitude. DME has the advantage of all-weather operation, and since the transponders are low-cost, even losses due to rain and ice are not a major concern. Preliminary design efforts in collaboration with Livermore produced an LDRD project to design and test prototypes of the balloon transponders and receivers and to prepare for field tests of the concepts using live transponders and local DME recievers in Spring 1999.

Cosite Problems in Army Communications

G. Canavan [(505) 667-3104] (PDO)

A study for the Army Science Board documented the "cosite" problems encountered when the DOD's approximately $10B worth of tactical frequency-hopping radios are used in close proximity. The problem is caused by the crude frequency spectrum of high-power transmitters and their uncorrelated hopping over inadequate frequency bands. We have identified and documented the problems, and have recommended procedures for tests and remediation.

Strategic Stability and Arms Control

G. Canavan [(505) 667-3104] (PDO)

Stability models are used to analyze the first strike stability of strategic and theater configurations and arms-control strategies. We have analyzed strategic force reductions together with the impact of de-alerting measures at each stage using the START I, II, and III models, and the results compared favorably with those of STRATCOM, NATO, and the Russian general staff. We also prepared a detailed analysis of the arms-control stability of the India-Pakistan configuration for the DOD, and we analyzed the feasibility and practicality of the “freedom to mix” offensive and defensive forces for the U.S. Congress.

Future Military Space

G. Canavan [(505) 667-3104] (PDO)

We participated in a year-long study of the future of military space for the U.S. Army and U.S. Air Force Scientific Advisory Boards. The study concentrated on deficiencies in transferring information from national assets to combat forces, requirements for improved real-time information on mobile forces, the orderly transition from the cold war emphasis on strategic concerns to current theater concerns, and the competition between wireless and fiber military and commercial communications capabilities in satisfying faster-than-expected demand growth. The results were reported to the highest levels of the Army and DOD.

Hypervelocity Impact Signatures

G. Canavan [(505) 667-3104] (PDO)

We performed a first principle analysis of the observables from 10 to 30 km/s impacts of 1-kg to 1,000-ton objects on solids, and we produced a set of predictions to guide the design and calibration of visible and active sensors for the Clementine asteroid impact experiment to be performed in 2001. We also inverted these predictions to infer the strength of meteors impacting the Earth’s atmosphere from their optical signatures. We are exploring this as a possible method for the U.S. Air Force Space Command, the agency responsible for satellite optical signal data reduction.

Defining Experiments for Atlas

J. Trainor [(505) 665-0906] (PDO); D. Bartsch, J. Benage, G. Kyrala, D. Oró, and J. Parker (P-22); C. Munson and B. Wood (P-24); R. Keinigs (XPA); and T. Taylor (MST-10)

A team of scientists was formed this year to assess, invent, and design an experimental agenda for the Atlas pulsed-power facility. Our goal is to understand and define weapons physics requirements and to use these requirements as the principal driver for defining the Atlas experimental program. This necessitates close collaboration with X-Division and Livermore colleagues. The team has been active in the following areas: defining and modeling of experimental concepts, defining diagnostic requirements, defining foundational experiments using Pegasus II and explosive pulsed-power, and articulating experimental requirements as they dictate Atlas machine design features.

We have now defined an initial ~200 shot suite of experiments for Atlas, including experimental topics in dynamic materials properties, implosion physics and hydrodynamics, dense ionized matter, and basic science. Specific experiments we are defining include hugoniot EOS experiments above 10 Mbar; multiple-shock EOS; adiabatic compressions to pressures well above 1 Mbar; dynamic phase transitions (especially melting); effects of strain and high strain-rate (in the ranges of 200% and

10^4 to 10^6 s^{-1} respectively); Rayleigh-Taylor instability mixing; dynamic friction at high interfacial velocity; Bell-Plesset instability; strongly-coupled plasma EOS and transport; hydrodynamics in strongly-coupled plasmas; magnetized target fusion; and experiments in ultrahigh magnetic fields (>1,000 Tesla).

Most of these experimental concepts have been modeled with one-dimensional computations and in some cases with two-dimensional calculations. These calculations have led to initial target designs and definition of diagnostic requirements. The team hosted an interlaboratory workshop in March to assess diagnostic issues for Atlas shock-driven experiments. Our examination of Atlas radiography requirements has led to development of an Atlas Radiographic Test (ART) object, which mocks up many of the features of realistic Atlas targets. We plan to field the ART object at various candidate radiographic sources to help guide the program's radiographic strategy; our first test used the 60-MeV betatron source at Arzamas-16 in Russia.

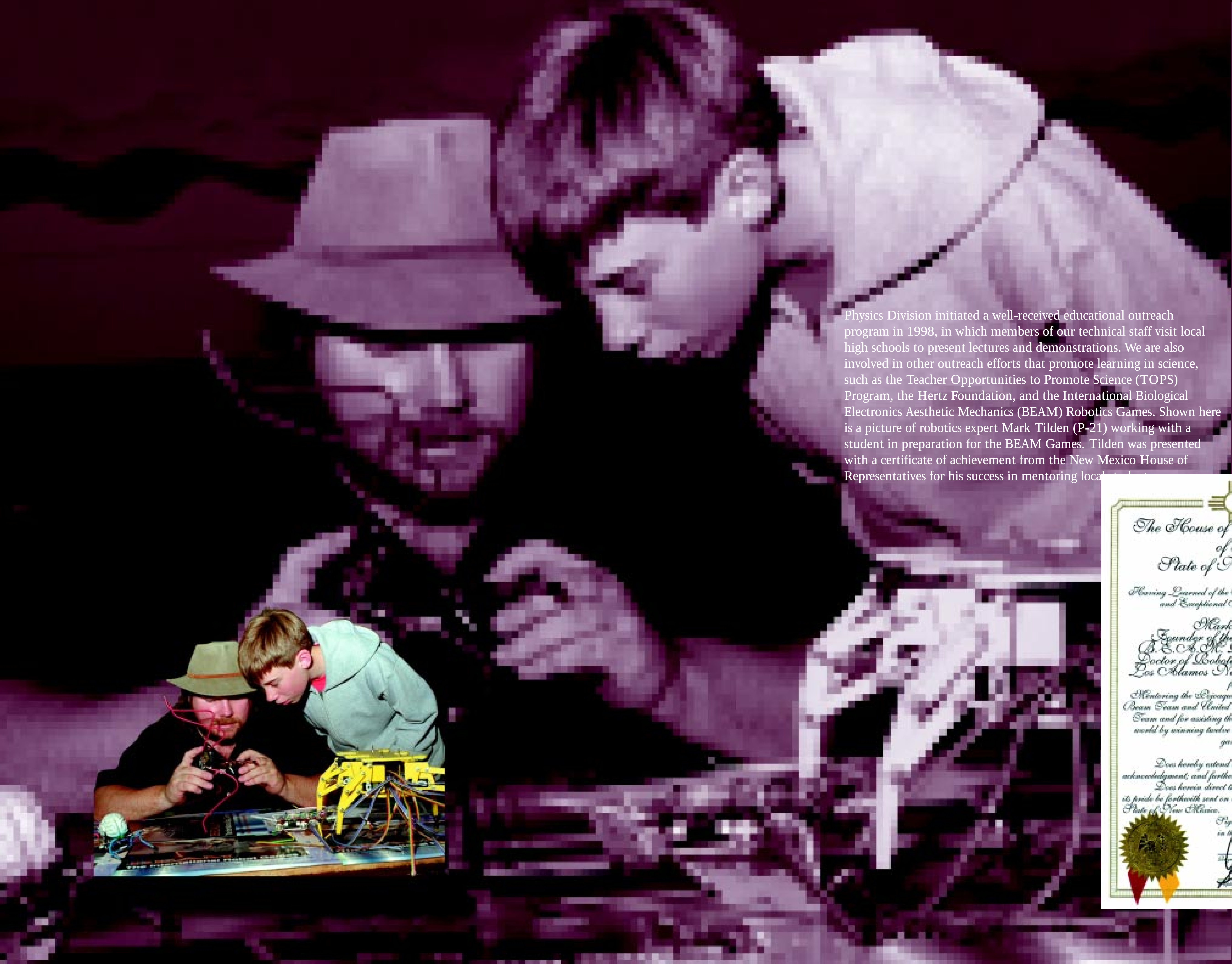
Surface Engineering with Plasmas and Particle Beams

Z. Falkenstein [(505)665-8390] (MST-8); D. J. Rej (P-DO); N. V. Gavrilov (Institute of Electrophysics in Yekaterinburg, Russia); S. Bugaev and D. Proskurovsky (Institute of High-Current Electronics in Tomsk, Russia); G. E. Remnev (Nuclear Physics Institute at Tomsk Polytechnic University); D. Karpov (Efremov Institute of Electrophysical Apparatus in St. Petersburg, Russia); D. Coates and J. Figueroa (DuPont Central Research); and J. V. Mantese (General Motors Research Laboratory)

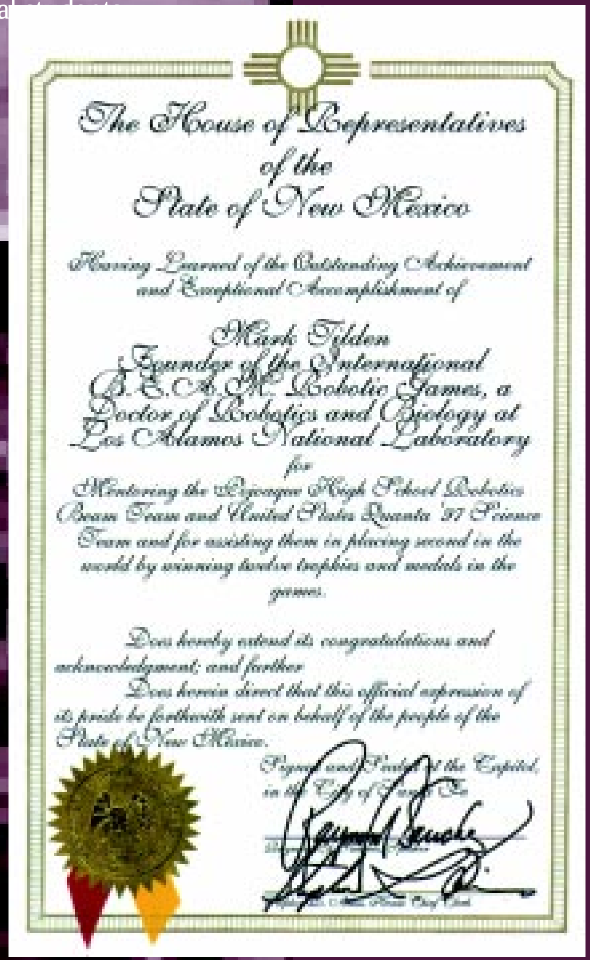
A partnership between four Russian Institutes, two U.S. corporations, and Los Alamos National Laboratory is underway to develop and commercialize five plasma-based methods for the modification of material surfaces. We are using cathodic arcs, hollow-cathode discharges, surface-barrier discharges, and intense electron and ion beams to enhance the surface properties (*e.g.*, hardness, toughness, wear, corrosion, electrical conductivity, and gas permeation) of a variety of commercially vital metal and polymer materials. Technical thrusts are equally divided between four areas: (1) plasma science; (2) plasma source development for commercialization; (3) material processing including ion implantation, coatings, and alloying; and (4) materials science.

Los Alamos highlights during 1998 include the delivery, installation, and operation of an ion source and implanter from the Institute of Electrophysics in Yekaterinburg at the Los Alamos Center for Materials Science. The plasma source is a pulsed-glow discharge with a cold hollow cathode in a weak magnetic field. Extraction and focusing of positive ions by an acceleration and ion-optical plate system enables the formation of a homogenous, large-area ion beam with an average current of up to 50 mA at acceleration voltages of up to 50 kV. With the cold cathode, reactive gases can be discharged with minimal materials sputtered from the cathode. Detailed characterization of ion current density over the ion source area has confirmed a uniform beam over the central 150 cm^2. Surface modification experiments by ion implantation of nitrogen into aluminum and chromium substrates have also been performed.

Appendices



Physics Division initiated a well-received educational outreach program in 1998, in which members of our technical staff visit local high schools to present lectures and demonstrations. We are also involved in other outreach efforts that promote learning in science, such as the Teacher Opportunities to Promote Science (TOPS) Program, the Hertz Foundation, and the International Biological Electronics Aesthetic Mechanics (BEAM) Robotics Games. Shown here is a picture of robotics expert Mark Tilden (P-21) working with a student in preparation for the BEAM Games. Tilden was presented with a certificate of achievement from the New Mexico House of Representatives for his success in mentoring local students.



The House of Representatives
of the
State of New Mexico

Having Learned of the Outstanding Achievement
and Exceptional Accomplishment of

Mark Tilden
Founder of the International
B.E.A.M. Robotic Games, a
Doctor of Robotics and Biology at
Los Alamos National Laboratory

for

Mentoring the Pojoaque High School Robotics Beam Team and United States Quanta '97 Science Team and for assisting them in placing second in the world by winning twelve trophies and medals in the games.

Does hereby extend its congratulations and acknowledgment; and further

Does herein direct that this official expression of its pride be forthwith sent on behalf of the people of the State of New Mexico.

Signed and Sealed at the Capitol,
in the City of Santa Fe

Appendix A
Physics Division Data
FY97–FY98

Group		FY97	FY98
P-21: Biophysics	Operating Costs[a]	4.4	4.9
	Staff Members[b]	13.7	16.0
	Graded Employees[c]	9.2	13.0
P-22: Hydrodynamic and X-Ray Physics	Operating Costs	12.5	12.1
	Staff Members	28.8	30.0
	Graded Employees	36.8	32.0
P-23: Neutron Science and Technology	Operating Costs	13.6	13.6
	Staff Members	40.0	36.0
	Graded Employees	20.0	23.0
P-24: Plasma Physics	Operating Costs	15.5	13.7
	Staff Members	40.3	36.0
	Graded Employees	41.2	31.0
P-25: Subatomic Physics	Operating Costs	10.6	10.7
	Staff Members	38.8	34.0
	Graded Employees	15.7	17.0
P-DO: Division Office	Operating Costs[d]	3.0	5.6
	Staff Members[e]	9.6	12.0
	Graded Employees[e]	8.6	11.0
	Total Operating Costs	59.6	60.7
	Capital Equipment Costs	4.9	2.3
	Total Costs	64.6	63.0
	Total Income	64.6	65.6
	Total Underrun/(Overrun)	0.0	2.6

[a] *Costs, income, and underrun/overrun are reported in $M.*

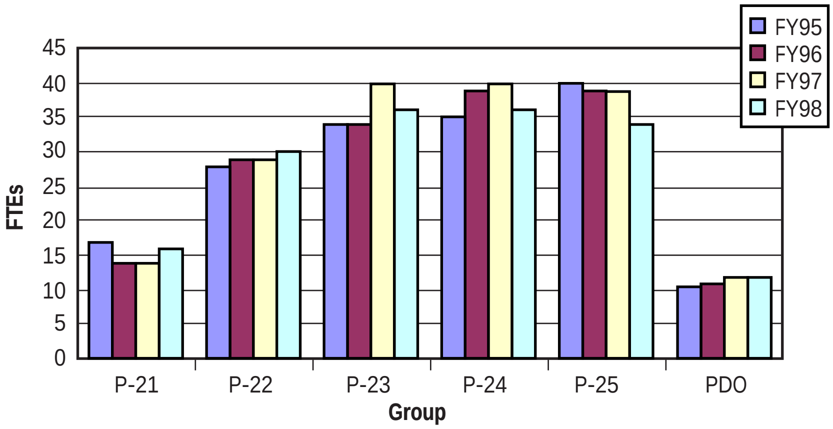
[b] *Staff Members are reported in full-time employees (FTEs) and include technical staff members (TSMs), TSM contractors, postdoctoral employees, and management.*

[c] *Graded Employees are reported in FTEs and include office support, technicians, graduate research assistants (GRAs), undergraduate students (UGSs), and contractors.*

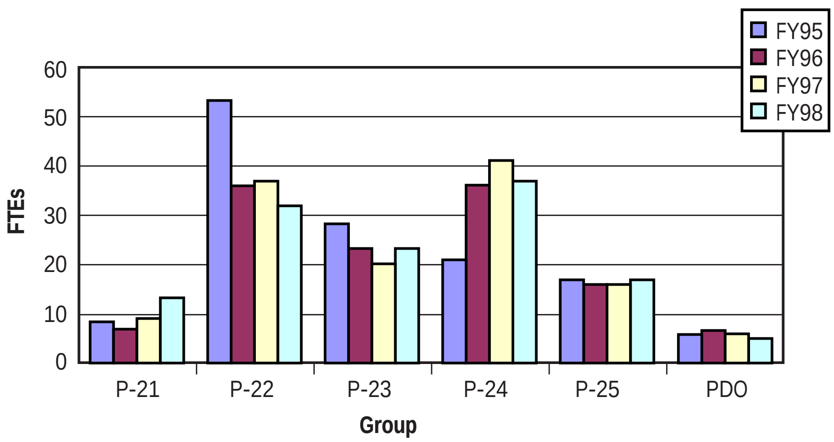
[d] *This value is the direct costs.*

[e] *This value includes indirect and direct FTEs.*

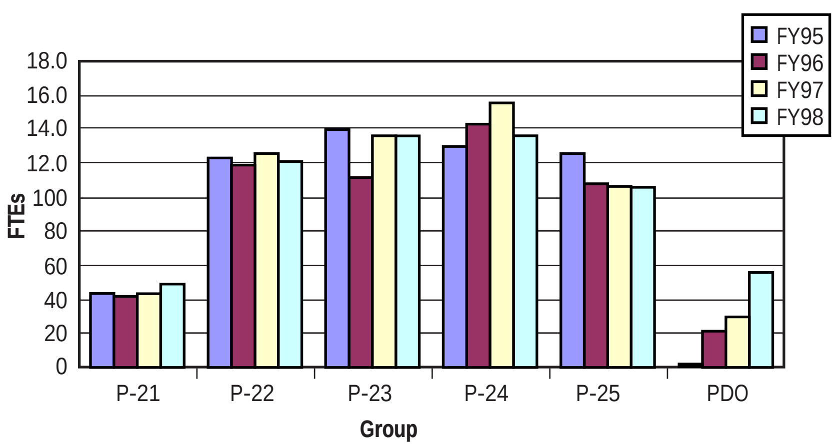
Physics Division Staff Members



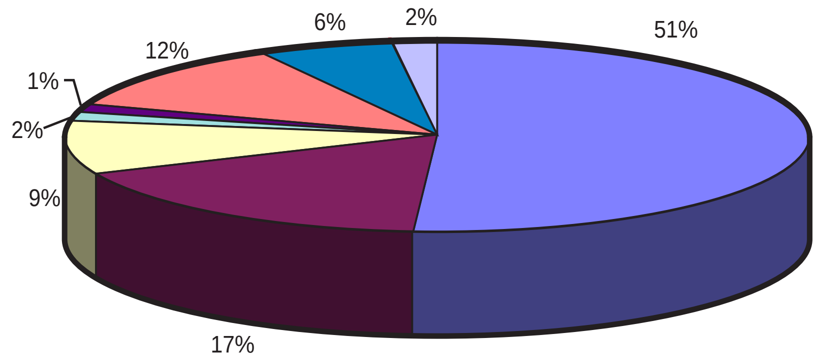
Physics Division Graded Employees



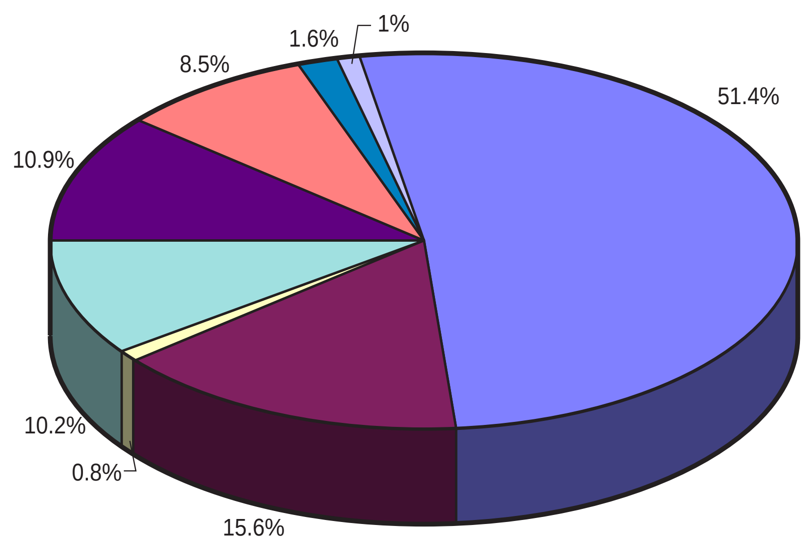
Physics Division Costs



FY97 Operating Costs: $59.7M



FY98 Operating Costs: $52.1M



- Weapons
- LANSCE/Energy Research
- Miscellaneous (General and Administrative, Environmental Management, *etc.*)
- Laboratory and University of California Directed Research and Development
- Atlas Construction
- Reimbursables
- Verification and Control
- Cooperative Research and Development Agreements (CRADAs)

Appendix B Publications and Conferences

1997 Journal Articles

M. Acciarri, *et al.* (L3 Collaboration), "Cross Section of Hadron Production in $\gamma\gamma$ Collisions at LEP," *Physics Letters B* 408, 450 (1997).

M. Acciarri, *et al.* (L3 Collaboration), "Hard-Photon Production at $\sqrt{s}$ = 161 and 172 GeV at LEP," *Physics Letters B* 413, 159 (1997).

M. Acciarri, *et al.* (L3 Collaboration), "Inclusive J, ψ' and χ_c Production in Hadronic Z Decays," *Physics Letters B* 407, 351 (1997).

M. Acciarri, *et al.* (L3 Collaboration), "K_s^0 and Λ Production in Quark and Gluon Jets at LEP," *Physics Letters B* 407, 389 (1997).

M. Acciarri, *et al.* (L3 Collaboration), "Measurement of $D_s^- \to \tau^- \bar{\nu}_\tau$ and a New Limit for $B^- \to \tau^- \bar{\nu}_\tau$," *Physics Letters B* 396, 327 (1997).

M. Acciarri, *et al.* (L3 Collaboration), "Measurement of Hadron and Lepton-Pair Production at 161 GeV < $\sqrt{s}$ < 172 GeV at LEP," *Physics Letters B* 407, 361 (1997).

M. Acciarri, *et al.* (L3 Collaboration), "Measurement of Inclusive w and η' Production in Hadronic Z Decays," *Physics Letters B* 393, 465 (1997).

M. Acciarri, *et al.* (L3 Collaboration), "Measurements of Mass, Width and Gauge Couplings of the W Boson at LEP," *Physics Letters B* 413, 176 (1997).

M. Acciarri, *et al.* (L3 Collaboration), "Measurement of W-Pair Cross Sections in e^+e^- Interactions at $\sqrt{s}$ = 172 GeV and W-Decay Branching Fractions," *Physics Letters B* 407, 419 (1997).

M. Acciarri, *et al.* (L3 Collaboration), "Neutral-Current 4-Fermion Production in e^+e^- Interactions at 130 GeV ≤ $\sqrt{s}$ ≤ 172 GeV," *Physics Letters B* 413, 191 (1997).

M. Acciarri, *et al.* (L3 Collaboration), "Pair-Production of W Bosons in e^+e^- Interactions at $\sqrt{s}$ = 161 GeV," *Physics Letters B* 398, 223 (1997).

M. Acciarri, *et al.* (L3 Collaboration), "Production of e, μ, and τ Pairs in Untagged Two-Photon Collisions at LEP," *Physics Letters B* 407, 341 (1997).

M. Acciarri, *et al.* (L3 Collaboration), "Production of Single W Bosons at LEP," *Physics Letters B* 403, 168 (1997).

M. Acciarri, *et al.* (L3 Collaboration), "QCD Studies and Determination of α_s in e^+e^- Collisions at $\sqrt{s}$ = 161 GeV and $\sqrt{s}$ = 172 GeV," *Physics Letters B* 404, 390 (1997).

M. Acciarri, *et al.* (L3 Collaboration), "Resonance Formation in the $\pi^+\pi^-\pi^0$ Final State in Two-Photon Collisions," *Physics Letters B* 413, 147 (1997).

M. Acciarri, *et al.* (L3 Collaboration), "Search for Anomalous Four-Jet Events in e^+e^- Annihilation at $\sqrt{s}$ = 130–172 GeV," *Physics Letters B* 411, 330 (1997).

M. Acciarri, *et al.* (L3 Collaboration), "Search for Excited Leptons in e^+e^- Annihilation at $\sqrt{s}$ = 161 GeV," *Physics Letters B* 401, 139 (1997).

M. Acciarri, *et al.* (L3 Collaboration), "Search for Exclusive *B* Decays to *J* and η or π^0 with the L3 Detector," *Physics Letters B* 391, 481 (1997).

M. Acciarri, *et al.* (L3 Collaboration), "Search for Heavy Neutral and Charged Leptons in e^+e^- Annihilation at $\sqrt{s}$ = 161 and $\sqrt{s}$ = 172 GeV," *Physics Letters B* 412, 189 (1997).

M. Acciarri, *et al.* (L3 Collaboration), "Search for Neutral *B* Meson Decays to Two Charged Leptons," *Physics Letters B* 391, 474 (1997).

M. Acciarri, *et al.* (L3 Collaboration), "Search for New Physics in Energetic Single Photon Production in e^+e^- Annihilation at the Z Resonance," *Physics Letters B* 412, 201 (1997).

M. Acciarri, *et al.* (L3 Collaboration), "Search for the Standard Model Higgs Boson in e^+e^- Interactions at $161 \leq \sqrt{s} \leq 172$ GeV," *Physics Letters B* 411, 373 (1997).

M. Acciarri, *et al.* (L3 Collaboration), "Single and Multi-Photon Events with Missing Energy in e^+e^- Collisions at 161 GeV < $\sqrt{s}$ < 172 GeV," *Physics Letters B* 415 299 (1997).

M. Acciarri, *et al.* (L3 Collaboration), "Study of Hadronic Events and Measurements of a_s between 30 and 91 GeV," *Physics Letters B* 411, 339 (1997).

M. Acciarri, *et al.* (L3 Collaboration), "Study of the Weak Charged Hadronic Current in *B* Decays," *Physics Letters B* 393, 477 (1997).

M. Acciarri, *et al.* (L3 Collaboration), "Upsilon Production in Z Decays," *Physics Letters B* 413 167 (1997).

S. Adler, M. S. Atiya, I.-H. Chiang, J. S. Frank, J. S. Haggerty, T. F. Kycia, K. K. Li, L. S. Littenberg, A. Sambamurti, A. Stevens, R. C. Strand, C. Witzig, W. C. Louis, D. S. Akerib, M. Ardebili, M. Convery, M. M. Ito,

D. R. Marlow, R. McPherson, P. D. Meyers, M. A. Selen, F. C. Shoemaker, A. J. S. Smith, E. W. Blackmore, D. A. Bryman, L. Felawka, A. Konaka, Y. Kuno, J. A. MacDonald, T. Numao, P. Padley, J.-M. Poutissou, R. Poutissou, J. Roy, A. S. Turcot, P. Kitching, T. Nakano, M. Rozon, and R. Soluk, "Observation of the Decay $K^+ \rightarrow \pi^+\mu^+\mu^-$," *Physical Review Letters* 79, 4756 (1997).

D. V. Ahluwalia, "Notes on the Kinematic Structure of the Three-Flavor Neutrino Oscillation Framework," *International Journal of Modern Physics A* 12, 5081 (1997).

D. V. Ahluwalia, "On a New Non-Geometric Element in Gravity," *General Relativity and Gravitation* 29, 1491 (1997).

D. V. Ahluwalia, "Three Quantum Aspects of Gravity," *Chinese Journal of Physics* 35, 804 (1997).

D. V. Ahluwalia and T. Goldman, "Interplay of Nonrelativistic and Relativistic Effects in Neutrino Oscillations," *Physical Review D* 56, 1698 (1997).

A. J. Allen, J. L. Terry, D. Garnier, J. A. Stillerman, and G. A. Wurden, "The High Resolution Video Capture System on the Alcator C-Mod Tokamak," *Review of Scientific Instruments* 68, 947 (1997).

C. Athanassopoulos, L. B. Auerbach, D. Bauer, R. D. Bolton, R. L. Burman, I. Cohen, D. O. Caldwell, B. D. Dieterle, J. B. Donahue, A. M. Eisner, A. Fazely, F. J. Federspiel, G. T. Garvey, M. Gray, R. M. Gunasingha, V. Highland, R. Imlay, K. Johnston, H. J. Kim, W. C. Louis, A. Lu, J. Margulies, G. B. Mills, K. McIlhany, W. Metcalf, R. A. Reeder, V. Sandberg, M. Schillaci, D. Smith, I. Stancu, W. Strossman, R. Tayloe, G. J. VanDalen, W. Vernon, Y.-X. Wang, D. H. White, D. Whitehouse, D. Works, Y. Xiao, and S. Yellin, "The Liquid Scintillator Neutrino Detector and LAMPF Neutrino Source," *Nuclear Instruments and Methods in Physics Research* 388, 149 (1997).

C. Athanassopoulos, L. B. Auerbach, R. L. Burman, D. O. Caldwell, E. Church, I. Cohen, B. D. Dieterle, J. B. Donahue, A. M. Eisner, A. Fazely, F. J. Federspiel, G. T. Garvey, M. Gray, R. M. Gunasingha, R. Imlay, K. Johnston, H. J. Kim, W. C. Louis, R. Majkic, K. McIlhany, W. Metcalf, G. B. Mills, R. A. Reeder, V. Sandberg, D. Smith, I. Stancu, W. Strossman, R. Tayloe, G. J. Van Dalen, W. Vernon, N. Wadia, J. Waltz, Y.-X. Wang, D. H. White, D. Works, Y. Xiao, and S. Yellin (LSND Collaboration), "Measurements of the Reactions $^{12}C(\nu_\mu,\mu^-)^{12}N_{g.s.}$ and $^{12}C(\nu_\mu,\mu^-)X$," *Physical Review C* 56, 2806 (1997).

C. Athanassopoulos, L. B. Auerbach, R. L. Burman, I. Cohen, D. O. Caldwell, B. D. Dieterle, J. B. Donahue, A. M. Eisner, A. Fazely, F. J. Federspiel, G. T. Garvey, M. Gray, R. M. Gunasingha, R. Imlay, K. Johnston, H. J. Kim, W. C. Louis, R. Majkic, J. Margulies, K. McIlhany,

W. Metcalf, G. B. Mills, R. A. Reeder, V. Sandberg, D. Smith, I. Stancu, W. Strossman, R. Tayloe, G. J. VanDalen, W. Vernon, N. Wadia, J. Waltz, Y.-X. Wang, D. H. White, D. Works, Y. Xiao, and S. Yellin (LSND Collaboration), "Measurements of the Reactions $^{12}C(\nu_e,e^-)^{12}N_{g.s.}$ and $^{12}C(\nu_e,e^-)^{12}N^*$," *Physical Review C* 55, 2078 (1997).

C. H. Bagley and G. G. Luther, "Preliminary Results of a Determination of the Newtonian Constant of Gravitation: A Test of the Kuroda Hypothesis," *Physical Review Letters* 78, 3047 (1997).

C. W. Barnes, "Neutron Activation Measurements over an Extremely Wide Dynamic Range (Invited)," *Review of Scientific Instruments* 68, 520 (1997).

C. W. Barnes, M. J. Loughlin, and T. Nishitani, "Neutron Activation for ITER," *Review of Scientific Instruments* 68, 577 (1997).

C. W. Barnes and A. L. Roquemore, "Neutron Source Strength Monitors for ITER," *Review of Scientific Instruments* 68, 573 (1997).

P. D. Barnes, W. Breunlich, H. Dennert, R. A. Eisenstein, W. Eyrich, H. Fischer, G. Franklin, J. Franz, R. von Frankenberg, R. Geyer, N. Hamann, D. W. Hertzog, T. Johansson, K. Kilian, M. Kirsch, R. A. Kraft, W. Oelert, B. Quinn, K. Röhrich, E. Rössle, H. Schmitt, R. Schumacher, T. Sefzick, F. Stinzing, R. Tayloe, and R. Todenhagen (PS185 Collaboration), "Measurement of the Reactions $\bar{p}p \rightarrow \bar{\Sigma}^+\Sigma^+$ and $\bar{p}p \rightarrow \bar{\Sigma}^-\Sigma^-$ Close to Threshold," *Physics Letters B* 402, 227 (1997).

F. B. Bateman, S. M. Grimes, N. Boukharouba, V. Mishra, C. E. Brient, R. S. Pedroni, T. N. Massey, and R. C. Haight, "Determination of the ^{29}Si Level Density from 3 to 22 MeV," *Physical Review C* 55, 133 (1997).

I. G. Bearden, H. Bøggild, J. Boissevain, J. Dodd, B. Erazmus, S. Esumi, C. W. Fabjan, D. Ferenc, D. E. Fields, A. Franz, J. J. Gaardhøje, A. G. Hansen, O. Hansen, D. Hardtke, H. van Hecke, E. B. Holzer, T. J. Humanic, P. Hummel, B. V. Jacak, R. Jayanti, H. Kalechofsky, M. Kaneta, M. Kopytine, Y. Y. Lee, M. Leltchouk, T. Ljubicic, B. Lörstad, N. Maeda, R. Malina, A. Medvedev, M. Murry, S. Nishimura, D. Reichhold, A. Sakaguchi, J. Simon-Gillo, J. Schmidt-Sørensen, W. Sondheim, M. Spegel, T. Sugitate, J. P. Sullivan, Y. Sumi, W. J. Willis, K. Wolf, N. Xu, and D. S. Zachary (NA44 Collaboration), "Collective Expansion in High Energy Heavy Ion Collisions," *Physical Review Letters* 78, 2080 (1997).

M. G. Bell, S. Batha, M. Beer, R. E. Bell, A. Belov, H. Berk, S. Bernabei, M. Bitter, B. Breizman, N. L. Bretz, R. Budny, C. E. Bush, J. Callen, S. Cauffman, C. S. Chang, Z. Chang, C. Z. Cheng, D. S. Darrow, R. O. Dendy, W. Dorland, H. Duong, P. C. Efthimion, D. Ernst, H. Evenson, N. J. Fisch, R. Fisher, R. J. Fonck, E. D. Fredrickson, G. Y. Fu, H. P. Furth, N. N. Gorelenkov, V. Ya. Goloborod'ko, B. Grek,

L. R. Grisham, G. W. Hammett, R. J. Hawryluk, W. Heidbrink, H. W. Herrmann, M. C. Herrmann, K. W. Hill, J. Hogan, B. Hooper, J. C. Hosea, W. A. Houlberg, M. Hughes, D. L. Jassby, F. C. Jobes, D. W. Johnson, R. Kaita, S. Kaye, J. Kesner, J. S. Kim, M. Kissick, A. V. Krasilnikov, H. Kugel, A. Kumar, N. T. Lam, P. Lamarche, B. LeBlanc, F. M. Levinton, C. Ludescher, J. Machuzak, R. P. Majeski, J. Manickam, D. K. Mansfield, M. Mauel, E. Mazzucato, J. McChesney, D. C., McCune, G. McKee, K. M. McGuire, D. M. Meade, S. S. Medley, D. R. Mikkelsen, S. V. Mirnov, D. Mueller, Y. Nagayama, G. A. Navratil, R. Nazikian, M. Okabayashi, M. Osakabe, D. K. Owens, H. K. Park, W. Park, S. F. Paul, M. P. Petrov, C. K. Phillips, M. Phillips, P. Phillips, A. T. Ramsey, B. Rice, M. H. Redi, G. Rewoldt, S. Reznik, A. L. Roquemore, J. Rogers, E. Ruskov, S. A. Sabbagh, M. Sasao, G. Schilling, G. L. Schmidt, S. D. Scott, I. Semenov, T. Senko, C. H. Skinner, T. Stevenson, E. J. Strait, B. C. Stratton, J. D. Strachan, W. Stodiek, E. Synakowski, H. Takahashi, W. Tang, G. Taylor, M. E. Thompson, S. von Goeler, A. von Halle, R. T. Walters, S. Wang, R. White, R. M. Wieland, M. Williams, J. R. Wilson, K. L. Wong, G. A. Wurden, M. Yamada, V. Yavorski, K. M. Young, L. Zakharov, M. C. Zarnstorff, and S. J. Zweben, “Deuterium-Tritium Plasmas in Novel Regimes in the Tokamak Fusion Test Reactor,” *Physics of Plasmas* 4, 1714 (1997).

V. M. Belyaev and M. B. Johnson, “Distribution of Valence Quarks and Light-Cone QCD Sum Rules,” *Physical Review D* 56, 1481 (1997).

T. R. Boehly, D. L. Brown, R. S. Craxton, R. L. Keck, J. P. Knauer, J. H. Kelly, T. J. Kessler, S. A. Kumpan, S. J. Loucks, S. A. Letzring, F. J. Marshall, R. L. McCrory, S. F. B. Morse, W. Seka, J. M. Soures, and C. P. Verdon, “Initial Performance Results of the OMEGA Laser System,” *Optics Communications* 133, 495 (1997).

P. Bogorad, E. J. Brash, G. D. Cates, W. J. Cummings, A. Gorelov, M. D. Hasinoff, O. Häusser, K. Hicks, R. Holmes, J. C. Huang, D. Krieger, K. S. Kumar, B. Larson, W. Lorenzon, J. McCracken, P. Michaux, H. Middleton, E. Saettler, D. Siegel, P. A. Souder, D. R. Swenson, J. Thywissen, D. Tupa, J. Ullom, X. Wang, and A. R. Young, “A Combined Polarized Target/Ionization Chamber for Measuring the Spin Dependence of Nuclear Muon Capture in Laser Polarized Muonic ^{3}He,” *Nuclear Instruments and Methods in Physics Research A* 398, 211 (1997).

E. Bosze, J. Simon-Gillo, J. Boissevain, J. Chang, and R. Seto, “Rohacell Foam as a Silicon Support Structure Material for the PHENIX Multiplicity Vertex Detector,” *Nuclear Instruments and Methods in Physics Research A* 400, 224 (1997).

C. L. Britton, Jr., W. L. Bryan, M. S. Emery, M. N. Ericson, M. S. Musrock, M. L. Simpson, M. C. Smith, J. W. Walker, A. L. Wintenberg, G. R. Young, M. D. Allen, L. G. Clonts, R. L. Jones, E. J. Kennedy, R. S. Smith, J. Boissevain, B. V. Jacak, D. Jaffe,

J. S. Kapustinsky, J. Simon-Gillo, J. P. Sullivan, H. van Hecke, and N. Xu, "Design and Performance of Beam Test Electronics for the PHENIX Multiplicity Vertex Detector," *IEEE Transactions on Nuclear Science* 44, 283 (1997).

M. L. Brooks, D. M. Lee, and W. E. Sondheim, "Alignment System for the PHENIX Muon Tracking Chambers," *IEEE Transactions on Nuclear Science* 44, 683 (1997).

R. L. Burman and P. Plischke, "Neutrino Fluxes from a High-Intensity Spallation Neutron Facility," *Nuclear Instruments and Methods in Physics Research A* 398, 147 (1997).

A. M. Buyko, N. P. Bidylo, V. K. Chernyshev, V. A. Demidov, S. F. Garanin, V. N. Kostyukov, A. A. Kulagin, A. I. Kuzyaev, A. B. Mezhevov, V. N. Mokhov, E. S. Pavlovskiy, A. A. Patrukhin, V. B. Yakubov, B. T. Yegorychev, J. W. Canada, C. A. Ekdahl, J. H. Goforth, J. C. King, I. R. Lindemuth, R. E. Reinovsky, P. Rodriguez, R. C. Smith, L. R. Veeser, and S. M. Younger, "Results of Russian/ U.S. High-Performance DEMG Experiment," *IEEE Transactions on Plasma Science* 25, 145 (1997).

A. M. Buyko, O. M. Burenkov, V. K. Chernyshev, S. F. Garanin, S. D. Kuznetsov, A. I. Kuzyayev, V. N. Mokhov, I. V. Morozov, E. S. Pavlovskiy, A. A. Petrukhin, A. I. Startsev, V. B. Yakubov, B. G. Anderson, C. A. Edkahl, J. Kammerdiner, I. R. Lindemuth, R. E. Reinovsky, P. Rodriguez, P. J. Sheehey, L. R. Veeser, S. M. Younger, and B. Zerwekh, "Changing Mass Liner System for Generation of Soft X-Rays," *Laser and Particle Beams* 15, 133 (1997).

S. E. Caldwell, S. S. Han, J. R. Joseph, T. L. Petersen, and C. S. Young, "Burn History Measurements in Laser Based Fusion," *Review of Scientific Instruments* 68, 603 (1997).

G. H. Canavan, "Optimal Detection of Near-Earth Object Threats," *Annals of the New York Academy of Sciences* 822, 539 (1997).

A. Castro and J. G. K. Williams, "Single-Molecule Detection of Specific Nucleic Acid Sequences in Unamplified Genomic DNA," *Analytical Chemistry* 69, 3915 (1997).

A. V. Chernyshev, A. B. Krasulin, V. D. Laptev, V. A. Matveev, and M. D. Cooper, "A Method for Improving the Constraint on the Tensor Coupling Constant in Radiative Pion Decay," *Modern Physics Letters A* 12, 1669 (1997).

R. E. Chrien, K. A. Klare, and T. J. Murphy, "Measurements of Neutron Spectra from Nova Targets," *Review of Scientific Instruments* 68, 607 (1997).

R. E. Chrien, K. A. Klare, T. J. Murphy, and L. A. Rauber, “Calibration and Operation of a Neutron Time-of-Flight Scintillator Array on Nova,” *Fusion Engineering and Design* 34, 577 (1997).

R. Clark, R. Becker-Szendy, C. B. Bratton, J. Breault, D. Casper, S. T. Dye, W. Gajewski, M. Goldhaber, T. J. Haines, P. G. Halverson, D. Kielczewska, W. R. Kropp, J. C. Learned, J. LoSecco, C. McGrew, S. Matsuno, R. S. Miller, L. Price, F. Reines, J. Schultz, H. W. Sobel, J. Stone, L. R. Sulak, R. Svoboda, and M. Vagins, “Atmospheric Muon Neutrino Fraction above 1 GeV,” *Physical Review Letters* 79, 345 (1997).

B. P. Cluggish, C. F. Driscoll, K. Avinash, and J. A. Helffrich, “Sawtooth Oscillations in a Damped/Driven Cryogenic Electron Plasma: Experiment and Theory,” *Physics of Plasmas* 4, 2062 (1997).

J. A. Cobble, R. P. Johnson, and R. J. Mason, “High-Intensity Illumination of an Exploding Foil,” *Physics of Plasmas* 4, 3006 (1997).

M. D. Cooper, “$\mu^+ \rightarrow e^+\gamma$ and Related Rare Decays,” *Nuclear Physics B* S59, 209 (1997).

H. A. Davis, R. R. Bartsch, J. C. Olson, D. J. Rej, and W. J. Waganaar, “Intense Ion Beam Optimization and Characterization with Infrared Imaging,” *Journal of Applied Physics* 82, 3223 (1997).

H. A. Davis, J. C. Olson, W. A. Reass, C. W. Barnes, R. R. Bartsch, D. M. Coates, J. W. Hunt, H. M. Schleinitz, R. H. Lovberg, and J. B. Greenly, “Progress toward a Microsecond Duration, Repetitively Pulsed, Intense-Ion Beam for Active Spectroscopic Measurements on ITER,” *Review of Scientific Instruments* 68, 332 (1997).

C. Decker, R. E. Turner, O. L. Landen, L. J. Suter, P. Amendt, H. N. Kornblum, B. A. Hammel, T. J. Murphy, J. Wallace, N. D. Delamater, P. Gobby, A. A. Hauer, G. R. Magelssen, J. A. Oertel, J. Knauer, F. J. Marshall, D. Bradley, W. Seka, and J. M. Soures, “Hohlraum Radiation Drive Measurements on the Omega Laser,” *Physical Review Letters* 79, 1491 (1997).

Z. Deng, I. Aksentijevich, J. E. Balow, T. Blake, M. Centola, X. Chen, F. S. Collins, N. Doggett, J. I. Rotter, M. Shohat, R. Sood, G. Wood, Y. Yokoyama, N. Zaks, D. L. Kastner, and P. Lise, “Identification of FMF Positional Candidate Genes within a 115-Kb Interval Defined by Historical Recombinants,” *American Journal of Human Genetics* 61, 1356 (1997).

R. C. Elton, H. R. Griem, B. L. Welch, A. L. Osterheld, R. C. Mancini, J. Knauer, G. Pien, R. G. Watt, J. A. Cobble, P. A. Jaanimagi, D. K. Bradley, J. A. Delettrez, and R. Epstein, “Satellite Spectral Lines in High Density Laser-Produced Plasmas,” *Journal of Quantitative Spectroscopy and Radiative Transfer* 58, 559 (1997).

M. A. Espy, J. M. O'Donnell, B. Davis, D. Dehnhard, J. L. Langenbrunner, B. Larson, M. Palarczyk, C.-M. Riedel, K. Wick, S. Blanchard, G. R. Burleson, W. R. Gibbs, B. Lail, B. Nelson, B. K. Park, Q. Zhao, W. J. Cummings, P. P. J. Delheij, B. K. Jennings, O. Häusser, R. Henderson, D. Thiessen, E. Brash, M. K. Jones, B. Brinkmöller, K. Maeda, F. Merrill, C. L. Morris, S. Penttilä, D. Swenson, D. Tupa, C. Bennhold, and S. S. Kamalov, "Asymmetries for Elastic Scattering of $\pi^{\pm}$ from Polarized ^{3}He at Δ Resonance Energies," *Physical Review C* 56, 2607 (1997).

S. Esumi, S. Chapman, H. van Hecke, and N. Xu, "Transverse Flow at Ultrarelativistic Energies," *Physical Review C* 55, R2163 (1997).

S. Esumi, U. Heinz, and N. Xu, "Collective Flow or Random Walk?" *Physics Letters B* 409, 479 (1997).

X. Feng, M. H. Holzscheiter, M. Charlton, J. Hangst, N. S. P. King, R. A. Lewis, J. Rochet, and Y. Yamazaki, "Capture and Cooling of Antiprotons," *Hyperfine Interactions* 109, 145 (1997).

J. C. Fernández, B. S. Bauer, K. S. Bradley, J. A. Cobble, R. G. Watt, B. Bezzerides, K. G. Estabrook, S. R. Goldman, D. B. Harris, E. L. Lindman, Jr., J. M. Wallace, and B. H. Wilde, "Increased Saturated Levels of Stimulated Brillouin Scattering of a Laser by Seeding a Plasma with an External Light Source," *Physical Review Letters* 81, 2252 (1997).

R. D. Fulton, J. C. Goldstein, M. E. Jones, J. M. Kinross-Wright, S. H. Kong, and D. C. Nguyen, "Enhanced Energy Loss of Short Pulses of Electrons in Plasma," *Journal of Applied Physics* 82, 2822 (1997).

R. Guckert, E. P. Chamberlin, D. W. Preston, V. D. Sandberg, D. Tupa, D. J. Vieira, H. Wollnik, and X. X. Zhao, "Coupling an Optical Trap to a Mass Separator," *Nuclear Instruments and Methods in Physics Research* 126, 383 (1997).

E. Hagberg, I. S. Towner, J. C. Hardy, V. T. Koslowsky, G. Savard, and S. Sterbenz, "Beta Decays of ^{44}V and ^{52}Co," *Nuclear Physics A* 613, 183 (1997).

M. H. Holzscheiter, G. Bendiscioli, A. Bertin, G. Bollen, M. Bruschi, C. Cesar, M. Charlton, M. Corradini, D. DePedis, M. Doser, J. Eades, R. Fedele, X. Feng, F. Galluccio, T. Goldman, J. S. Hangst, R. Hayano, D. Horváth, R. J. Hughes, N. S. P. King, K. Kirsebom, H. Knudsen, V. Lagomarsino, R. Landua, G. Laricchia, R. A. Lewis, E. Lodi-Rizzini, M. Macri, G. Manuzio, U. Marconi, M. R. Masullo, J. P. Merrison, S. P. Møller, G. L. Morgan, M. M. Nieto, M. Piccinini, R. Poggiani, A. Rotondi, G. Rouleau, P. Salvini, N. Semprini-Cesari, G. A. Smith, C. M. Surko, G. Testera, G. Torelli, E. Uggerhøj, V. G. Vaccaro, L. Venturelli, A. Vitale, E. Widmann, T. Yamazaki, Y. Yamazaki,

D. Zanello, and A. Zoccoli, “Antihydrogen Production and Precision Experiments,” *Nuclear Physics B* (S56A), 336 (1997).

M. H. Holzscheiter, G. Bendiscioli, A. Bertin, G. Bollen, M. Bruschi, C. Cesar, M. Charlton, M. Corradini, D. DePedis, M. Doser, J. Eades, R. Fedele, X. Feng, F. Galluccio, T. Goldman, J. S. Hangst, R. Hayano, D. Horváth, R. J. Hughes, N. S. P. King, K. Kirsebom, H. Knudsen, V. Lagomarsino, R. Landua, G. Laricchia, R. A. Lewis, E. Lodi-Rizzini, M. Macri, G. Manuzio, U. Marconi, M. R. Masullo, J. P. Merrison, S. P. Møller, G. L. Morgan, M. M. Nieto, M. Piccinini, R. Poggiani, A. Rotondi, G. Rouleau, P. Salvini, N. Semprini-Cesari, G. A. Smith, C. M. Surko, G. Testera, G. Torelli, E. Uggerhøj, V. G. Vaccaro, L. Venturelli, A. Vitale, E. Widmann, T. Yamazaki, Y. Yamazaki, D. Zanello, and A. Zoccoli, “Antihydrogen Production and Precision Experiments: The ATHENA Collaboration,” *Hyperfine Interactions* 109, 1 (1997).

W.-C. Hsi, K. Kwiatkowski, G. Wang, D. S. Bracken, E. Cornell, D. S. Ginger, V. E. Viola, N. R. Yoder, R. G. Korteling, F. Gimeno-Nogures, E. Ramakrishnan, D. Rowland, S. J. Yennello, M. J. Huang, W. G. Lynch, M. B. Tsang, H. Xi, Y. Y. Chu, S. Gushue, L. P. Remsberg, K. B. Morley, and H. Breuer, “Formation of Hot Nuclei with GeV π and π^- Beams,” *Physical Review Letters* 79, 817 (1997).

P. R. Huffman, N. R. Roberson, W. S. Wilburn, C. R. Gould, D. G. Haase, C. D. Keith, B. W. Raichle, M. L. Seely, and J. R. Walston, “Test of Parity-Conserving, Time-Reversal Invariance using Polarized Neutrons and Nuclear Spin Aligned Holmium,” *Physical Review C* 55, 2684 (1997).

R. J. Hughes, “Quantum Security is Spookily Certain,” *Nature* 385, 17 (1997).

D. Husson, C. Bauer, I. Baumann, C. Colledani, J. Conway, P. Delpierre, F. Djama, W. Dulinski, M. Edwards, A. Fallou, K. K. Gan, R. S. Gilmore, E. Grigoriev, G. Halewell, S. Han, T. Hessing, J. Hrubec, H. Kagan, D. Kania, R. Kass, K. T. Knoepfle, M. Krammer, T. J. Llewellyn, P. F. Manfredi, D. Meier, L. S. Pan, H. Pernegger, M. Pernicka, V. Re, S. Roe, D. Roff, A. Rudge, S. Schnetzer, V. Speziall, R. Stone, R. J. Tapper, R. Tesarek, W. Trischuk, R. Turchetta, G. B. Thomson, P. Weilhammer, H. Ziock, and M. Zoeller, “Neutron-Irradiation of CVD-Diamond Samples for Tracking Detectors,” *Nuclear Instruments and Methods in Physics Research* 388, 421 (1997).

C. G. Idzorek and H. Oona, “Properties of Plasma Radiation Diagnostics,” *Review of Scientific Instruments* 68, 1065 (1997).

B. H. Jared, T. A. Dow, K. P. Garrard, G. M. Moorefield, C. Barnes, R. D. Day, D. J. Hatch, L. J. Salzer, and G. Rivera,“Fabrication of Hydrodynamic Instability Targets,” *Fusion Technology* 31, 501 (1997).

L. C. Johnson, C. W. Barnes, A. Krasilnikov, F. B. Marcus, and T. Nishitani, “Neutron Diagnostics for ITER,” *Review of Scientific Instruments* 68, 569 (1997).

G. Kahrimanis, G. Burleson, C. M. Chen, B. C. Clark, K. Dhuga, D. J. Ernst, J. A. Faucett, H. T. Fortune, S. Hama, A. Hussein, M. F. Jiang, K. W. Johnson, L. K. Kerr, S. Mathews, J. McGill, C. F. Moore, S. Mordechai, C. L. Morris, J. O’Donnell, M. Snell, M. Rawool-Sullivan, L. Ray, C. Whitley, and A. L. Williams, “Pion-Nucleus Elastic Scattering on ^{12}C, ^{40}Ca, ^{90}Zr, and ^{208}Pb at 400 and 500 MeV,” *Physical Review C* 55, 2533 (1997).

K. Kaimi, H. Bøggild, J. Boissevain, M. Cherney, J. Dodd, S. Esumi, C. W. Fabjan, D. E. Fields, A. Franz, B. Holzer, T. J. Humanic, B. Jacak, R. Jayanti, H. Kalechofsky, T. Kobayashi, Y. Y. Lee, M. Leltchouk, B. Lörstad, N. Maeda, A. Medvedev, A. Miyabayashi, M. Murray, S. Nishimura, E. Noteboom, S. U. Pandey, F. Piuz, V. Polychronakos, M. Potekhin, G. Poulard, A. Sakaguchi, J. Schmidt-Sørensen, J. Simon-Gillo, W. Sondheim, T. Sugitate, J. P. Sullivan, Y. Sumi, H. van Hecke, W. J. Willis, K. Wolf, and N. Xu, “Multiplicity Dependence of the Pion Source in S + A Collisions at the CERN SPS,” *Zeitschrift für Physik C* 75, 619 (1997).

J. Kapustinsky, J. Boissevain, E. Bosze, C. Britton, J. Chang, D. Clark, M. Emery, N. Ericson, S. Y. Fung, B. Jacak, D. Jaffe, L. Marek, R. Seto, J. Simon-Gillo, M. Simpson, R. Smith, J. Sullivan, Y. Takahashi, H. van Hecke, J. Walker, and N. Xu, “A Multiplicity-Vertex Detector for the PHENIX Experiment at RHIC,” *Nuclear Instruments and Methods in Physics Research A* 392, 192 (1997).

V. V. Ketlerov, A. A. Goverdovski, V. A. Khryachkov, V. F. Mitrofanov, Y. B. Ostapenko, R. C. Haight, P. E. Koehler, S. M. Grimes, and R. S. Smith, “Detailed Study of Double-Differential Cross-Sections for the ^{17}O(n,α)^{14}C Reaction,” *Nuclear Physics A* 621, C243 (1997).

P. Kitching, T. Nakano, M. Rozon, R. Soluk, S. Adler, M. S. Atiya, I.-H. Chiang, J. S. Frank, J. S. Haggerty, T. F. Kycia, K. K. Li, L. S. Littenberg, A. Sambamurti, A. Stevens, R. C. Strand, C. Witzig, W. C. Louis, D. S. Akerib, M. Ardebili, M. Convery, M. M. Ito, D. R. Marlow, R. A. McPherson, P. D. Meyers, M. A. Selen, F. C. Shoemaker, A. J. S. Smith, E. W. Blackmore, D. A. Bryman, L. Felawka, A. Konaka, Y. Kuno, J. A. MacDonald, T. Numao, P. Padley, J.-M. Poutissou, R. Poutissou, J. Roy, and A. S. Turcot, “Observation of the Decay $K^+ \rightarrow \pi^+\gamma\gamma$,” *Physical Review Letters* 79, 4079 (1997).

P. G. Kwiat, “Hyper-Entangled States,” *Journal of Modern Optics* 44, 2173 (1997).

G. A. Kyrala, S. Evans, J. Jimerson, and J. C. Fernández, "Time Resolved Side Scatter Diagnostics at NOVA," *Review of Scientific Instruments* 68, 664 (1997).

S. K. Lamoreaux, "Demonstration of the Casimir Force in the 0.6 to 6 μm Range," *Physical Review Letters* 78, 5 (1997).

S. K. Lamoreaux, "Thermalization of Trapped Ions: A Quantum Perturbation Approach," *Physical Review A* 56, 4970 (1997).

S. K. Lamoreaux and V. K. Ignatovich, "Tidal Pressure Induced Neutrino Emission as an Energy Dissipation Mechanism in Binary Pulsar Systems," *Journal of the Physical Society of Japan* 66, 1225 (1997).

R. J. Leeper, G. A. Chandler, G. W. Cooper, M. S. Derzon, D. L. Fehl, D. E. Hebron, A. R. Moats, D. D. Noack, J. L. Porter, L. E. Ruggles, C. L. Ruiz, J. A. Torres, M. D. Cable, P. M. Bell, C. A. Clower, B. A. Hammel, D. H. Kalantar, V. P. Karpenko, R. L. Kauffman, J. D. Kilkenny, F. D. Lee, R. A. Lerche, B. J. MacGowan, M. J. Moran, M. B. Nelson, W. Olson, T. J. Orzechowski, T. W. Phillips, D. Ress, G. L. Tietbohl, J. E. Trebes, R. J. Bartlett, R. Berggren, S. E. Caldwell, R. E. Chrien, B. H. Failor, J. C. Fernández, A. Hauer, G. Idzorek, R. G. Hockaday, T. J. Murphy, J. Oertel, R. Watt, M. Wilke, D. K. Bradley, J. Knauer, R. D. Petrasso, and C. K. Li, "Target Diagnostic System for the National Ignition Facility (Invited)," *Review of Scientific Instruments* 68, 868 (1997).

M. Lo Vetere, L. Bertolotto, A. Buzzo, P. Debevec, D. Drijard, S. Easo, R. A. Eisenstein, C. Evangelista, W. Eyrich, T. Fearnley, M. Ferroluzzi, H. Fischer, J. Franz, R. Geyer, N. H. Hamann, P. G. Harris, D. W. Hertzog, S. A. Hughes, A. Johansson, T. Johansson, R. T. Jones, K. Kilian, K. Kirsebom, A. Klett, H. Korsmo, M. Macri, M. Marinelli, M. Moosburger, B. Mouellic, W. Oelert, S. Ohlsson, A. Palano, S. Passaggio, J.-M. Perreau, M. G. Pia, S. Pomp, M. Price, P. E. Reimer, J. Ritter, E. Robutti, K. Röhrich, M. Rook, T. Sefzick, E. Rössle, A. Santroni, H. Schmitt, O. Steinkamp, F. Stinzing, B. Stugu, R. Tayloe, M. Tscheulin, H. J. Urban, H. Wirth, and H. Zipse, "Phi-Phi Excitation-Function at LEAR," *Nuclear Physics B* (S56A), 256 (1997).

L. Y. Lowie, J. D. Bowman, B. E. Crawford, P. P. J. Delheij, T. Haseyama, J. N. Knudson, A. Masaike, Y. Matsuda, G. E. Mitchell, S. I. Penttilä, H. Postma, N. R. Roberson, S. J. Seestrom, E. I. Sharapov, S. L. Stephenson, Y.-F. Yen, and V. W. Yuan, "Neutron Resonance Spectroscopy of ^{107}Ag and ^{109}Ag," *Physical Review C* 56, 90 (1997).

R. J. Maqueda, C. W. Barnes, S. S. Han, P. A. Staples, and R. S. Wagner, "Proton Recoil Detector of Fusion Neutrons using Natural Diamond," *Review of Scientific Instruments* 68, 624 (1997).

D. N. McKinsey, C. R. Brome, J. S. Butterworth, R. Golub, K. Habicht, P. R. Huffman, S. K. Lamoreaux, C. E. H. Mattoni, and J. M. Doyle, "Fluorescence Efficiencies of Thin Scintillating Films in the Extreme Ultraviolet Spectral Region," *Nuclear Instruments and Methods in Physics Research B* 13, 351 (1997).

A. McPherson, J. Cobble, A. B. Borisov, B. D. Thompson, F. Omenetto, K. Boyer, and C. K. Rhodes, "Evidence of Enhanced Multiphoton (248 nm) Coupling from Single-Pulse Energy Measurements of Xe(L) Emission Induced from Xe Clusters," *Journal of Physics B* 13, L767 (1997).

W. Melnitchouk and J.-C. Peng, "Large-x d/u Ratio in W-Boson Production," *Pysics Letters B* 400, 220 (1997).

T. B. Mitchell, M. M. Schauer, and D. C. Barnes, "Observation of Spherical Focus in an Electron Penning Trap," *Physical Review Letters* 78, 58 (1997).

D. V. Morgan, M. Sagurton, and R. J. Bartlett, "Single-Photon Multiple Ionization of Neon in the K-Edge Region," *Physical Review A* 55, 1113 (1997).

J. C. Mosher, E. R. Flynn, A. Quinn, A. Weir, U. Shahani, R. J. P. Bain, P. Maas, and G. B. Donaldson, "Fetal Magnetocardiography: Methods for Rapid Data Reduction," *Review of Scientific Instruments* 68, 1587 (1997).

T. J. Murphy, R. E. Chrien, and K. A. Klare, "Interpretation of Neutron Time-of-Flight Signals from Current-Mode Detectors," *Review of Scientific Instruments* 68, 610 (1997).

T. J. Murphy, R. E. Chrien, and K. A. Klare, "Neutron Time-of-Flight Signals from Expanding or Contracting Spherical Sources," *Review of Scientific Instruments* 68, 614 (1997).

T. Nishitani, M. Isobe, G. A. Wurden, R. E. Chrien, H. Harano, K. Tobita, and Y. Kusama, "Triton Burnup Measurements using Scintillating Fiber Detectors on JT-60U," *Fusion Engineering and Design* 34-35, 563 (1997).

A. W. Obst, R. E. Chrien, and M. D. Wilke, "Colliding Plasma Neutron Production at Trident," *Review of Scientific Instruments* 68, 618 (1997).

J. A. Oertel, T. Archuleta, C. G. Peterson, and F. J. Marshall, "Dual Microchannel Plate Module for a Gated Monochromatic X-Ray Imager," *Review of Scientific Instruments* 68, 789 (1997).

J. A. Oertel and C. G. Peterson, "Los Alamos Pinhole Camera (LAPC): A New Flexible X-Ray Pinhole Camera," *Review of Scientific Instruments* 68, 786 (1997).

B. G. Ofenloch, R. A. Giannelli, B. G. Ritchie, J. M. O'Donnell, J. N. Knudson, C. L. Morris, C. M. Kormanyos, A. Saunders, J. Z. Williams, R. A. Lindgren, and B. L. Clausen, "Pion-Nucleus Spin-Flip Strength at Low and Resonance Energies," *Physical Review C* 55, 1295 (1997).

H. Ohnishi, I. G. Bearden, H. Bøggild, J. Bossevain, J. Dodd, B. Erazmus, S. Esumi, C. W. Fabjan, D. Ferenc, D. E. Fields, A. Franz, J. J. Gaardhøje, A. G. Hansen, O. Hansen, D. Hardtke, H. Vanhecke, E. B. Holzzer, T. J. Humanic, P. Hummel, B. V. Jacak, R. Jayanti, M. Kaneta, M. Kopytine, M. Leltchouk, A. Ljubicic, B. Lörstad, N. Maeda, R. Malina, A. Medvedev, M. Murray, S. Nishimura, H. Ohnishi, G. Paic, S. U. Pandey, F. Piuz, J. Pluta, V. Polychronakos, M. Potekhin, G. Poulard, D. Reichhold, A. Sakaguchi, J. Simon-Gillo, J. Schmidt-Sørensen, W. Sondheim, M. Spegel, T. Sugitate, J. P. Sullivan, Y. Sumi, W. J. Willis, K. Wolf, N. Xu, and D. S. Zachary, "Multiplicity Dependence of Pion Source Size in Heavy-Ion Collisions," *Progress of Theoretical Physics Supplement* 129, 161 (1997).

W. M. Parsons, E. O. Ballard, R. R. Bartsch, J. F. Benage, G. A. Bennett, R. L. Bowers, D. W. Bowman, J. H. Brownell, J. C. Cochrane, H. A. Davis, C. A. Ekdahl, R. F. Gribble, J. R. Griego, P. D. Goldstone, M. E. Jones, W. B. Hinckley, K. W. Hosack, R. J. Kasik, H. Lee, E. A. Lopez, I. R. Lindemuth, M. D. Monroe, R. W. Moses, Jr., S. A. Ney, D. Platts, W. A. Reass, H. R. Salazar, G. M. Sandoval, D. W. Scudder, J. S. Shlachter, M. C. Thompson, R. J. Trainor, G. A. Valdez, R. G. Watt, G. A. Wurden, and S. M. Younger, "The Atlas Project—A New Pulsed-Power Facility for High Energy Density Physics Experiments," *IEEE Transactions on Plasma Science* 25, 205 (1997).

E. A. Pasyuk, V. Y. Alexakhin, S. I. Gogolev, K. O. Oganesyan, C. L. Morris, J. M. O'Donnell, M. W. Rawool-Sullivan, M. K. Jones, F. F. Guber, A. I. Reshetin, and I. I. Strakovsky, "$\pi^+ + d \rightarrow p + p$ Reaction between 18 and 44 MeV," *Physical Review C* 55, 1026 (1997).

P. K. Patel, J. S. Wark, D. J. Heading, A. Djaoui, S. J. Rose, O. Renner, and A. Hauer, "Simulation of X-Ray Line Transfer in a Cylindrically Expanding Plasma," *Journal of Quantitative Spectroscopy and Radiative Transfer* 57, 683 (1997).

P. K. Patel, J. S. Wark, O. Renner, A. Djaoui, S. J. Rose, D. J. Heading, and A. Hauer, "Experimental and Simulated Profiles of the Al XIII Ly-α Resonance Line from a Cylindrically Expanding Plasma," *Journal of Quantitative Spectroscopy and Radiative Transfer* 58, 835 (1997).

J.-C. Peng and G. T. Garvey, "Drell-Yan Process and the Sea Quark Distributions," *Chinese Journal of Physics* 35, 832 (1997).

J. W. Phillips, R. M. Leahy, and J. C. Mosher, "MEG-Based Imaging of Focal Neuronal Current Sources," *IEEE Transactions on Medical Imaging* 16, 338 (1997).

J. W. Phillips, R. M. Leahy, J. C. Mosher, and B. Timsari, "Imaging Neural Activity using MEG and EEG," *IEEE Engineering in Medicine and Biology* 16, 34 (1997).

D. J. Rej, H. A. Davis, M. Nastasi, J. C. Olson, E. J. Peterson, R. D. Reiswig, K. C. Walter, R. W. Stinnett, G. E. Remnev, and V. K. Struts, "Surface Modification of AISI-4620 Steel with Intense Pulsed Ion Beams," *Nuclear Instruments and Methods in Physics Research* B 127, 987 (1997).

D. J. Rej, H. A. Davis, J. C. Olson, G. E. Remnev, A. N. Zakoutaev, V. A. Ryzhkov, V. K. Struts, I. F. Isakov, V. A. Shulov, N. A. Nochevnaya, R. Stinnett, E. L. Neau, K. Yatsui, and W. Jiang, "Materials Processing with Intense Pulsed Ion Beams," *Journal of Vacuum Science and Technology A* 15, 1089 (1997).

D. J. Rej, R. J. Faehl, and J. N. Matossian, "Key Issues in Plasma-Source Ion Implantation," *Surface and Coatings Technology* 96, 45 (1997).

H. Sarafian, M. A. Kagarlis, and M. B. Johnson, "Klein-Gordon Equation in a Coupled-Channels Description of Elastic and Inelastic Scattering," *Physical Review C* 56, 1500 (1997).

M. Sasao, G. A. Wurden, and D. K. Mansfield, "Spectroscopic Measurement of the Doppler Broadening Region of He II Line Emission of DT Plasmas using Impurity Pellets," *Fusion Engineering and Design* 34-35, 333 (1997).

M. M. Schauer, T. B. Mitchell, M. H. Holzscheiter, and D. C. Barnes, "Electron Penning Trap for the Generation of High Density Non-Neutral Plasmas," *Review of Scientific Instruments* 68, 3340 (1997).

J. T. Scheuer, K. C. Walter, R. A. Adler, and W. G. Horne, "Commercial Plasma Source Ion Implantation Facility," *Surface and Coatings Technology* 93, 192 (1997).

I. Schlichting and J. Berendzen, "Out of the Blue: The Photocycle of the Photoactive Yellow Protein," *Structure* 5, 735 (1997).

I. Schlichting, J. Berendzen, K. Chu, A. M. Stock, R. M. Sweet, D. Ringe, G. A. Petsko, M. Davies, E. J. Mueller, D. Benson, and S. Sligar, "Crystal-Structures of Intermediates Occurring along the Reaction Pathway of Cytochrome P450(CAM)," *FASEB Journal* 11, P2 (1997).

D. M. Schmidt, J. S. George, S. I. Penttilä, A. Caprihan, and E. Fukushima, "Diffusion Imaging with Hyperpolarized ^{3}He Gas," *Journal of Magnetic Resonance* 129, 184 (1997).

G. S. Selwyn, C. A. Weiss, F. Sequeda, and C. Huang, "Particle Contamination Formation in Magnetron Sputtering Processes," *Vacuum Science and Technology A* 15, 2023 (1997).

A. P. Serebrov, V. A. Mityukhlyaev, A. A. Zakharov, T. Bowles, G. Greene, and J. Sromicki, "Solid Deuterium Source of Ultracold Neutrons based on a Pulsed Spallation Source," *JETP Letters* 66, 802 (1997).

C. H. Skinner, E. Amarescu, G. Ascione, W. Blanchard, C. W. Barnes, S. H. Batha, M. Beer, M. G. Bell, R. Bell, M. Bitter, N. L. Bretz, R. Budny, C. E. Bush, R. Camp, M. Casey, J. Collins, M. Cropper, Z. Chang, D. S. Darrow, H. H. Duong, R. Durst, P. C. Efthimion, D. Ernst, N. Fisch, R. J. Fonck, E. Fredrickson, G. Y. Fu, H. P. Furth, C. A. Gentile, M. Gibson, J. Gilbert, B. Grek, L. R. Grisham, G. Hammett, R. J. Hawryluk, H. W. Herrmann, K. W. Hill, J. Hosea, A. Janos, D. L. Jassby, F. C. Jobes, D. W. Johnson, L. C. Johnson, J. Kamperschroer, M. Kalish, H. Kugel, J. Langford, S. Langish, P. H. LaMarche, B. LeBlanc, F. M. Levinton, J. Machuzak, R. Majeski, J. Manikam, D. K. Mansfield, E. Mazzucato, K. M. McGuire, R. Mika, G. McKee, D. M. Meade, S. S. Medley, D. R. Mikkelsen, H. E. Mynick, D. Mueller, A. Nagy, R. Nazikian, M. Ono, D. K. Owens, H. Park, S. F. Paul, G. Pearson, M. Petrov, C. K. Phillips, S. Raftopoulos, A. Ramsey, R. Raucci, M. H. Redi, G. Rewoldt, J. Rogers, A. L. Roquemore, E. Ruskov, S. A. Sabbagh, G. Schilling, J. F. Schivell, G. L. Schmidt, S. D. Scott, S. Sesnic, B. C. Stratton, J. D. Strachan, T. Stevenson, D. P. Stotler, E. Synakowski, H. Takahashi, W. Tang, G. Taylor, W. Tighe, J. R. Timberlake, A. von Halle, S. von Goeler, R. T. Walters, R. B. White, J. R. Wilson, J. Winston, K. L. Wong, K. M. Young, M. C. Zarnstorff, and S. J. Zweben, "Plasma Wall Interaction and Tritium Retention in TFTR," *Journal of Nuclear Materials* 241, 214 (1997).

R. S. Smith, E. J. Kennedy, R. G. Jackson, M. L. Simpson, C. L. Britton, Jr., W. L. Bryan, U. Jagadish, G. R. Young, B. V. Jacak, J. Kapustinsky, and A. Oscarson, "A Discriminator with a Current-Sum Multiplicity Output for the PHENIX Multiplicity Vertex Detector," *IEEE Transactions on Nuclear Science* 44, 389 (1997).

J. A. Stillerman, T. W. Fredian, K. A. Klare, and G. Manduchi, "MDSplus Data Acquisition System," *Review of Scientific Instruments* 68, 939 (1997).

R. W. Stotzer, T. Bürger, P. D. Barnes, B. Bassalleck, A. R. Berdoz, M. Burger, R. E. Chrien, C. A. Davis, G. E. Diebold, H. En'yo, H. Fischer, G. B. Franklin, J. Franz, L. Gan, D. R. Gill, T. Iijima, K. Imai, P. Koran, M. Landry, L. Lee, J. Lowe, R. Magahiz, A. Masaike, R. McCrady,

F. Merrill, C. A. Meyer, J. M. Nelson, K. Okada, S. A. Page, P. H. Pile, B. P. Quinn, W. D. Ramsay, E. Rössle, A. Rusek, R. Sawafta, H. Schmitt, R. A. Schumacher, R. L. Stearns, I. R. Sukaton, R. Sutter, J. J. Szymanski, F. Takeutchi, W. T. H. van Oers, D. M. Wolfe, K. Yamamoto, M. Yosoi, V. J. Zeps, and R. Zybert (BNL E836 Collaboration), "Search for the *H*-Dibaryon in ^{3}He(K^{-},K^{+})Hn," *Physical Review Letters* 78, 3646 (1997).

J. D. Strachan, S. Batha, M. Beer, M. G. Bell, R. E. Bell, A. Belov, H. Berk, S. Bernabei, M. Bitter, B. Breizman, N. L. Bretz, R. Budny, C. E. Bush, J. Callen, S. Cauffman, C. S. Chang, Z. Chang, C. Z. Cheng, D. S. Darrow, R. O. Dendy, W. Dorland, H. Duong, P. C. Efthimion, D. Ernst, H. Evenson, N. J. Fisch, R. Fisher, R. J. Fonck, E. D. Fredrickson, G. Y. Fu, H. P. Furth, N. N. Gorelenkov, V. Y. Goloborod'ko, B. Grek, L. R. Grisham, G. W. Hammett, R. J. Hawryluk, W. Heidbrink, H. W. Herrmann, M. C. Herrmann, K. W. Hill, J. Hogan, B. Hooper, J. C. Hosea, W. A. Houlberg, M. Hughes, D. L. Jassby, F. C. Jobes, D. W. Johnson, R. Kaita, S. Kaye, J. Kesner, J. S. Kim, M. Kissick, A. V. Krasilnikov, H. Kugel, A. Kumar, N. T. Lam, P. Lamarche, B. LeBlanc, R. M. Levinton, C. Ludescher, J. Machuzak, R. P. Majeski, J. Manickam, D. K. Mansfield, M. Mauel, E. Mazzucato, J. McChesney, D. C. McCune, G. McKee, K. M. McGuire, D. M. Meade, S. S. Medley, D. R. Mikkelsen, S. V. Mirnov, D. Mueller, Y. Nagayama, G. A. Navratil, R. Nazikian, M. Okabayashi, M. Osakabe, D. K. Owens, H. K. Park, W. Park, S. F. Paul, M. P. Petrov, C. K. Phillips, M. Phillips, P. Phillips, A. T. Ramsey, B. Rice, M. H. Redi, G. Rewoldt, S. Reznik, A. L. Roquemore, J. Rogers, E. Ruskov, S. A. Sabbagh, M. Sasao, G. Schilling, G. L. Schmidt, S. D. Scott, I. Semenov, T. Senko, C. H. Skinner, T. Stevenson, E. J. Strait, B. C. Stratton, W. Stodiek, E. Synakowski, H. Takahashi, W. Tang, G. Taylor, M. E. Thompson, S. von Goeler, A. von Halle, R. T. Walters, S. Wang, R. White, R. M. Wieland, M. Williams, J. R. Wilson, K. L. Wong, G. A. Wurden, M. Yamada, V. Yavorski, K. M. Young, L. Zakharov, M. C. Zarnstorff, and S. J. Zweben, "TFTR DT Experiments," *Plasma Physics and Controlled Fusion* 39, B103 (1997).

S. Supek and C. J. Aine, "Spatiotemporal Modeling of Neuromagnetic Data. 1. Multisource Location versus Time-Course Estimation Accuracy," *Human Brain Mapping* 5, 139 (1997).

S. Supek and C. J. Aine, "Spatiotemporal Modeling of Neuromagnetic Data. 2. Multisource Resolvability of a MUSIC-Based Location Estimator," *Human Brain Mapping* 5, 154 (1997).

T. N. Taddeucci, J. Ullmann, L. J. Rybarcyk, G. W. Butler, and T. E. Ward, "Total Cross Sections for Production of ^{7}Be, ^{22}Na, and ^{24}Na in p + ^{7}Li and p + ^{27}Al reactions at 495 and 795 MeV," *Physical Review C* 55, 1551 (1997).

T. C. Terwilliger and J. Berendzen, "Bayesian Correlated MAD Phasing," *Acta Crystallographica D* 53, 571 (1997).

Y. Tosaka, S. Satoh, K. Suzuki, T. Sugii, N. Nakayama, H. Ehara, G. A. Woffinden, and S. A. Wender, "Measurements and Analysis of Neutron-Reaction-Induced Charges in a Silicon Surface Region," *IEEE Transactions On Nuclear Science* 44, 173 (1997).

M. Tuszewski, "Inductive Electron Heating Revisited," *Physics of Plasmas* 4, 1922 (1997).

M. Tuszewski, J. T. Scheuer, and R. A. Adler, "A Pulsed Inductively Coupled Plasma Source for Plasma-Based Ion Implantation," *Surface and Coatings Technology* 93, 203 (1997).

H. Vonach, A. Pavlik, A. Wallner, M. Drosg, R. C. Haight, D. M. Drake, and S. Chiba, "Spallation Reactions in ^{27}Al and ^{56}Fe Induced by 800 MeV Protons," *Physical Review C* 55, 2458 (1997).

K. C. Walter, M. Nastasi, and C. Munson, "Adherent Diamond-Like Carbon Coatings on Metals via Plasma Source Ion Implantation," *Surface and Coatings Technology* 93, 287 (1997).

G. Wang, A. Botvina, D. S. Bracken, E. Renshaw Foxford, W. A. Friedman, R. G. Korteling, K. Kwiatkowski, R. Legrain, K. B. Morley, E. C. Pollacco, V. E. Viola, and C. Volant, "Time Dependence of Multifragmentation in Light-Ion-Induced Reactions," *Physics Letters B* 393, 270 (1997).

J. S. Wark, S. J. Rose, P. K. Patel, A. Djaoui, O. Renner, and A. Hauer, "Astrophysically Relevant Experiments on Radiation Transfer through Plasmas with Large Velocity Gradients," *Physics of Plasmas* 4, 2004 (1997).

R. G. Watt, D. C. Wilson, R. E. Chrien, R. V. Hollis, P. L. Gobby, R. J. Mason, R. A. Kopp, R. Lerche, D. H. Kalantar, B. MacGowan, M. B. Nelson, T. Phillips, P. W. McKenty, and O. Willi, "Foam-Buffered Spherical Implosions at 527 nm," *Physics of Plasmas* 4, 1379 (1997).

W. S. Wilburn, "A High-Accuracy Beam Current Integrator for Fast Spin-Flip Experiments," *Nuclear Instruments and Methods in Physics Research A* 394, 257 (1997).

M. D. Wilke, J. C. Fernández, R. R. Berggren, R. F. Horton, D. S. Montgomery, J. A. Faulkner, L. D. Looney, and J. R. Jimerson, "Full Aperture Backscatter Station Imager Diagnostics System for Far-Field Imaging of Laser Plasma Instabilities on NOVA," *Review of Scientific Instruments* 68, 672 (1997).

G. A. Wurden, "A Radiation-Hard, Steady State, Digital Imaging Bolometer System," *Fusion Engineering and Design* 34-35, 301 (1997).

G. A. Wurden, B. J. Peterson, and S. Sudo, "Design of an Imaging Bolometer System for the Large Helical Device," *Review of Scientific Instruments* 68, 766 (1997).

Y.-F. Yen, J. D. Bowman, L. Y. Lowie, Y. Masuda, G. E. Mitchell, and S. I. Penttilä, "Determination of the Gamma-Ray Background in a Pulsed Epithermal Neutron Beam," *Nuclear Instruments and Methods in Physics Research A* 397, 365 (1997).

J. Zhang, K. Kwiatkowski, D. Bonser, M. Fatyga, S. D. Coon, K. Stith, V. E. Viola, L. W. Woo, and S. J. Yennello, "Complex Fragment Emission in the 200-MeV ^{4}He + ^{nat}Ag, ^{197}Au Reactions," *Physics Review C* 56, 1918 (1997).

X. M. Zhao, M. S. Gulley, H. C. Bryant, C. E. M. Strauss, D. J. Funk, A. Stintz, D. C. Rislove, G. A. Kyrala, W. B. Ingalls, and W. A. Miller, "Nonresonant Excess Photon Detachment of Negative Hydrogen Ions," *Physical Review Letters* 78, 1656 (1997).

M. M. Zoeller, W. Adam, C. Bauer, I. Baumann, C. Colledani, J. Conway, P. Delpierre, F. Djama, W. Dulinski, A. Fallou, D. Fish, K. K. Gan, E. Grigoriev, Kass, K. T. Knöpfle, M. Krammer, P. F. Manfredi, D. Meier, L. S. Pan, H. Pernegger, M. Pernicka, V. Re, S. Roe, D. Roff, A. Rudge, M. Schaeffer, S. Schnetzer, V. Speziali, R. Stone, R. J. Tapper, R. Tesarek, G. B. Thomson, W. Trischuk, R. Turchetta, A. M. Walsh, P. Weilhammer, and H. Ziock, "Performance of CVD Diamond Microstrip Detectors under Particle Irradiation," *IEEE Transactions on Nuclear Science* 44, 815 (1997).

1998 Journal Articles

W. P. Abfalterer, F. B. Bateman, F. S. Dietrich, C. Elster, R. W. Finlay, W. Glockle, J. Golak, R. C. Haight, D. Huber, G. L. Morgan, and H. Witala, "Inadequacies of the Nonrelativistic 3*n* Hamiltonian in Describing the N + D Total Cross-Section," *Physical Review Letters* 81, 57 (1998).

M. Acciarri, *et al.* (L3 Collaboration), "Angular Multiplicity Fluctuations in Hadronic Z-Decays and Comparison to QCD Models and Analytical Calculations," *Physics Letters B* 428, 186 (1998).

M. Acciarri, *et al.* (L3 Collaboration), "Determination of the Number of Light Neutrino Species from Single-Photon Production at LEP," *Physics Letters B* 431, 199 (1998).

M. Acciarri, *et al.* (L3 Collaboration), "K_s^0 Production and λ Production in Quark and Gluon Jets at LEP," *Physics Letters B* 427, 409 (1998).

M. Acciarri, *et al.* (L3 Collaboration), "Local Multiplicity Fluctuations in Hadronic Z-Decay," *Physics Letters B* 429, 375 (1998).

M. Acciarri, *et al.* (L3 Collaboration), "Measurement of η'(958) Formation in Two-Photon Collisions at LEP1," *Physics Letters B* 418, 399 (1998).

M. Acciarri, *et al.* (L3 Collaboration), "Measurement of Radiative Bhabha and Quasi-Real Compton-Scattering," *Physics Letters B* 439, 183 (1998).

M. Acciarri, *et al.* (L3 Collaboration), "Measurement of Tau-Polarization at LEP," *Physics Letters B* 429, 387 (1998).

M. Acciarri, *et al.* (L3 Collaboration), "Measurement of the Anomalous Magnetic and Electric-Dipole Moments of the Tau-Lepton," *Physics Letters B* 434, 169 (1998).

M. Acciarri, *et al.* (L3 Collaboration), "Measurement of the Average Lifetime of B-Hadrons in Z-Decays," *Physics Letters B* 416, 220 (1998).

M. Acciarri, *et al.* (L3 Collaboration), "Measurement of the $B_d^0 - \overline{B}_d^0$ Oscillation Frequency," *European Physical Journal C* 5, 195 (1998).

M. Acciarri, *et al.* (L3 Collaboration), "Measurement of the Effective Weak Mixing Angle by Jet-Charge Asymmetry in Hadronic Decays of the Z-Boson," *Physics Letters B* 439, 225 (1998).

M. Acciarri, *et al.* (L3 Collaboration), "Measurement of the Inclusive Charmless Semileptonic Branching Fraction of Beauty Hadrons and a Determination of $|V_{ub}|$ at LEP," *Physics Letters B* 436, 174 (1998).

M. Acciarri, *et al.* (L3 Collaboration), "Measurement of the Michel Parameters and the Average Tau-Neutrino Helicity from Tau-Decays at LEP," *Physics Letters B* 438, 405 (1998).

M. Acciarri, *et al.* (L3 Collaboration), "Measurement of the Weak Dipole-Moments of the Tau-Lepton," *Physics Letters B* 426, 207 (1998).

M. Acciarri, *et al.* (L3 Collaboration), "Measurement of W-Pair Cross-Sections in e^+e^- Interactions at $\sqrt{s}$ = 183 GeV and W-Decay Branching Fractions," *Physics Letters B* 436, 437 (1998).

M. Acciarri, *et al.* (L3 Collaboration), "Missing Mass Spectra in Hadronic Events from e^+e^- Collisions at $\sqrt{s}$ = 161–172 GeV and Limits on Invisible Higgs Decays," *Physics Letters B* 418, 389 (1998).

M. Acciarri, *et al.* (L3 Collaboration), "Photon Structure Functions and Azimuthal Correlations of Lepton Pairs in Tagged Gamma-Gamma Collisions," *Physics Letters B* 438, 363 (1998).

M. Acciarri, *et al.* (L3 Collaboration), "Production of Single W-Bosons in e^+e^- Interactions at $130 \leq \sqrt{s} \leq 183$ GeV and Limits on Anomalous WW-Gamma Couplings," *Physics Letters B* 436, 417 (1998).

M. Acciarri, *et al.* (L3 Collaboration), "Search for Neutral Higgs Bosons of the Minimal Supersymmetric Standard Model in e^+e^- Interactions at $\sqrt{s}$ = 130–183 GeV," *Physics Letters B* 436, 389 (1998).

M. Acciarri, *et al.* (L3 Collaboration), "Search for New Physics Phenomena in Fermion-Pair Production at LEP," *Physics Letters B* 433, 163 (1998).

M. Acciarri, *et al.* (L3 Collaboration), "Search for Scalar Leptons, Charginos, and Neutralinos in e^+e^- Collisions at $\sqrt{s}$ = 161–172 GeV," *European Physical Journal C* 4, 207 (1998).

M. Acciarri, *et al.* (L3 Collaboration), "Search for the Standard Model Higgs-Boson in e^+e^- Interactions at $\sqrt{s}$ = 183 GeV," *Physics Letters B* 431, 437 (1998).

M. Acciarri, *et al.* (L3 Collaboration), "Study of Anomalous $zz\gamma$ and $z\gamma\gamma$ Couplings at LEP," *Physics Letters B* 436, 187 (1998).

M. Acciarri, *et al.* (L3 Collaboration), "Study of the Hadronic Photon Structure-Function F-2(γ) at LEP," *Physics Letters B* 436, 403 (1998).

M. Acciarri, *et al.* (L3 Collaboration), "Test of CP Invariance in $Z \rightarrow \mu^+\mu^-\gamma$ Decay," *Physics Letters B* 436, 428 (1998).

M. Acciarri, *et al.* (L3 Collaboration), "Upper Limit on the Lifetime Difference of Short-Lived and Long-Lived B_s^0 Mesons," *Physics Letters B* 438, 417 (1998).

D. L. Adams, N. Akchurin, L. V. Alexeeva, N. I. Belikov, B. E. Bonner, A. Bravar, J. Bystricky, M. D. Corcoran, J. D. Cossairt, J. Cranshaw, A. A. Derevschikov, H. En'yo, H. Funahashi, Y. Goto, O. A. Grachov, D. P. Grosnick, D. A. Hill, T. Iijima, K. Imai, Y. Itow, K. Iwatani, Yu. V. Kharlov, K. W. Krueger, K. Kuroda, M. Laghai, F. Lehar, A. de Lesquen, D. Lopiano, G. C. Luehring, T. Maki, S. Makino, A. Masaike, Yu. A. Matulenko, A. P. Meschanin, A. Michalowicz, D. H. Miller, K. Miyake, T. Nagamine, F. Nessi-Tedaldi, M. Nessi, C. Nguyen, L. V. Nogach, S. B. Nurushev, Y. Ohashi, Y. Onel, D. I. Patalakha, G. Pauletta, A. Penzo, G. F. Rappazzo, A. L. Read, J. B. Roberts, L. van Rossum, V. L. Rykov, N. Saito, G. Salvato, P. Schiavon, T. Shima, J. Skeens, V. L. Solovyanov, H. Spinka, R. W. Stanek, R. Takashima, F. Takeutchi, N. Tamura, N. Tanaka,

D. G. Underwood, A. N. Vasiliev, J. L. White, S. Yamashita, A. Yokosawa, T. Yoshida, and A. Zanetti, “Measurement of Single Spin Asymmetry in η-Meson Production in $p\uparrow p$ and $\bar{p}\uparrow p$ Interactions in the Beam Fragmentation Region at 200 GeV/c,” *Nuclear Physics B* 510, 3 (1998).

S. Adler, M. S. Atiya, I.-H. Chiang, J. S. Frank, J. S. Haggerty, T. F. Kycia, K. K. Li, L. S. Littenberg, A. Sambamurti, A. Stevens, R. C. Strand, C. Witzig, W. C. Louis, D. S. Akerib, M. Ardebili, M. Convery, M. M. Ito, D. R. Marlow, R. McPherson, P. D. Meyers, M. A. Selen, F. C. Shoemaker, A. J. S. Smith, E. W. Blackmore, D. A. Bryman, L. Felawka, A. Konaka, Y. Kuno, J. A. MacDonald, T. Numao, P. Padley, J.-M. Poutissou, R. Poutissou, J. Roy, A. S. Turcot, P. Kitching, T. Nakano, M. Rozon, and R. Soluk, “Upper Limit on the Decay $K^+ \rightarrow e^+ \nu \text{-} \mu^+ \mu^-$,” *Physical Review D* 5801, 2003 (1998).

D. V. Ahluwalia, “Can General-Relativistic Description of Gravitation be Considered Complete?” *Modern Physics Letters A* 13, 1393 (1998).

D. V. Ahluwalia and C. Burgard, “Interplay of Gravitation and Linear Superposition of Different Mass Eigenstates,” *Physical Review D* 57, 4724 (1998).

V. Y. Alexakhin, S. I. Gogolev, M. K. Khankhasayev, Z. B. Kurmanov, K. O. Oganesyan, E. A. Pasyuk, C. L. Morris, J. M. O’Donnell, M. W. Rawool-Sullivan, M. K. Jones, F. F. Guber, and A. I. Reshetin, “$\pi^+ + {}^{12}C$ Elastic-Scattering between 18 and 44 MeV,” *Physical Review C* 57, 2409 (1998).

C. Athanassopoulos, L. B. Auerbach, R. L. Burman, D. O. Caldwell, E. D. Church, I. Cohen, J. B. Donahue, A. Fazely, F. J. Federspiel, G. T. Garvey, R. M. Gunasingha, R. Imlay, K. Johnston, H. J. Kim, W. C. Louis, R. Majkic, K. McIlhany, W. Metcalf, G. B. Mills, R. A. Reeder, V. Sandberg, D. Smith, I. Stancu, W. Strossman, R. Tayloe, G. J. VanDalen, W. Vernon, N. Wadia, J. Waltz, D. H. White, D. Works, Y. Xiao, and S. Yellin, “Results on $\nu_\mu \rightarrow \nu_e$ Oscillations from Pion Decay In-Flight Neutrinos,” *Physical Review C* 58, 2489 (1998).

P. D. Bangert, M. D. Cooper, and S. K. Lamoreaux, “Enhancement of Superthermal Ultracold Neutron-Production by Trapping Cold Neutrons,” *Nuclear Instruments and Methods in Physics Research Section A* 410, 264 (1998).

C. W. Barnes, H. S. Bosch, H. W. Hendel, A. G. A. Huibers, D. L. Jassby, R. W. Motley, E. B. Nieschmidt, T. Saito, J. D. Strachan, M. Bitter, R. V. Budny, K. W. Hill, D. K. Mansfield, D. C. McCune, R. Nazikian, H. K. Park, A. T. Ramsey, S. D. Scott, G. Taylor, and M. C. Zarnstorff, “Triton Burnup Measurements and Calculations on TFTR,” *Nuclear Fusion* 38, 597 (1998).

I. G. Bearden, H. Bøggild, J. Boissevain, J. Dodd, B. Erazmus, S. Esumi, C. W. Fabjan, D. Ferenc, D. E. Fields, A. Franz, J. Gaardhøje, M. Hamelin, A. G. Hansen, O. Hansen, D. Hardtke, H. van Hecke, E. B. Holzer, T. J. Humanic, P. Hummel, B. V. Jacak, R. Jayanti, K. Kaimi, M. Kaneta, T. Kohama, M. Kopytine, M. Leltchouk, A. Ljubicic, B. Lörstad, N. Maeda, R. Malina, A. Medvedev, M. Murray, H. Ohnishi, G. Paic, S. U. Pandey, F. Piuz, J. Pluta, V. Polychronakos, M. Potekhin, G. Poulard, D. Reichhold, A. Sakaguchi, J. Simon-Gillo, J. Schmidt-Sørensen, W. Sondheim, M. Spegel, T. Sugitate, J. P. Sullivan, Y. Sumi, W. J. Willis, K. L. Wolf, N. Xu, and D. S. Zachary, "High-Energy Pb + Pb Collisions Viewed by Pion Interferometry," *Physical Review C* 58, 1656 (1998).

I. G. Bearden, H. Bøggild, J. Boissevain, J. Dodd, S. Esumi, C. W. Fabjan, D. E. Fields, A. Franz, A. G. Hansen, E. B. Holzer, T. J. Humanic, B. V. Jacak, R. Jayanti, H. Kalechofsky, Y. Y. Lee, M. Leltchouk, B. Lörstad, N. Maeda, A. Medvedev, A. Miyabayashi, M. Murray, S. Nishimura, S. U. Pandey, F. Piuz, V. Polychronakos, M. Potekhin, G. Poulard, A. Sakaguchi, M. Sarabura, M. Spegel, J. Simon-Gillo, W. Sondheim, T. Sugitate, J. P. Sullivan, Y. Sumi, H. van Hecke, W. J. Willis, K. Wolf, and N. Xu, "Proton and Antiproton Distributions at Midrapidity in Proton-Nucleus and Sulfur-Nucleus Collisions," *Physical Review C* 57, 837 (1998).

V. M. Belyaev and M. B. Johnson, "Pion Light-Cone Wave Functions and Light-Front Quark-Model," *Physics Letters B* 423, 379 (1998).

A. R. Berdoz, J. Birchall, J. D. Bowman, J. R. Campbell, C. A. Davis, A. A. Green, P. W. Green, A. A. Hamian, D. C. Healey, R. Helmer, S. Kadantsev, Y. Kuznetsov, R. Laxdal, L. Lee, C. D. P. Levy, R. E. Mischke, S. A. Page, W. D. Ramsay, S. D. Reitzner, G. Roy, P. W. Schmor, A. M. Sekulovich, J. Soukup, G. M. Stinson, T. Stocki, V. Sum, N. A. Titov, W. T. H. van Oers, R. J. Woo, and A. N. Zelenski, "Parity Violation in Proton-Proton Scattering," *Nuclear Physics A* 629, C433 (1998).

L. A. Bernstein, J. A. Becker, W. Younes, D. E. Archer, K. Hauschild, G. D. Johns, R. O. Nelson, W. S. Wilburn, and D. M. Drake, "Probing Reaction Dynamics With the Pt-196(N,Xn γ) Reactions for $x \leq 15$," *Physical Review C* 57, R2799 (1998).

L. Bitteker, "Nuclear-Induced Electrical-Conductivity in ^{3}He," *Journal of Applied Physics* 83, 4018 (1998).

K. I. Blomqvist, W. U. Boeglin, R. Böhm, M. Distler, R. Edelhoff, J. Friedrich, R. Geiges, M. K. Jones, M. Kahrau, M. Korn, H. Kramer, K. W. Krygier, V. Kunde, M. Kuss, A. Liesenfeld, K. Merle, C. L. Morris, R. Neuhausen, E. A. J. M. Offermann, Th. Pospischil, M. Potokar, R. D. Ransome, A. W. Richter, B. G. Ritchie, A. Rokavec, G. Rosner, J. Ryckebusch, P. Sauer, S. Schardt, B. Vodenik, A. Wagner, Th. Walcher, S. Wolf, and M. K. Yadav, "Investigation of Short-Range Nucleon-

Nucleon Correlations using the Reaction $^{12}C(e,e'pp)$ in Close to 4π Geometry," *Physics Letters B* 421, 71 (1998).

J. S. Brooks, L. Engel, J. Cothern, J. A. Simmons, M. J. Hafich, W. Lewis, S. Gallegos, D. Devore, B. Marshall, M. Grover, G. Leach, C. H. Mielke, D. Rickel, D. Clark, M. Fowler, J. King, L. Tabaka, J. Detwiler, E. C. Clark, R. G. Clark, A. Dzurak, B. Kane, N. Miura, O. Tatsenko, V. Platonov, and A. Bykov, "Dirac-II Series in 800 T Fields: Reflectivity Measurements on Low-Dimensional, Low Electron-Density Materials," *Physica B* 246, 50 (1998).

J. Brzychczyk, E. C. Pollacco, C. Volant, D. Lacroix, R. Lagrain, K. Kwiatkowski, D. S. Bracken, K. B.Morley, E. Renshaw Foxford, V. E. Viola, N. R.Yoder, R. G. Korteling, J. Cugnon, and H. Breuer, "Diversity of Fragment Sizes in Fultiframentation of Gold Nuclei Induced by Relativistic ^{3}He ions," *Physics Review C* 58, R1372 (1998).

W. T. Buttler, R. J. Hughes, P. G. Kwiat, S. K. Lamoreaux, G. G. Luther, G. L. Morgan, J. E. Nordholt, C. G. Peterson, and C. M. Simmons, "Practical Free-Space Quantum Key Distribution Over 1 km," *Physical Review Letters* 81, 3283 (1998).

W. T. Buttler, R. J. Hughes, P. G. Kwiat, G. G. Luther, G. L Morgan, J. E. Nordholt, C. G. Peterson, and C. M. Simmons, "Free-Space Quantum-Key Distribution," *Physical Review A* 57, 2379 (1998).

C. A. Cagliardi, E. A. Hawker, R. E. Tribble, D. D. Koetke, P. M. Nord, P. L. McGaughey, and C. N. Brown, "Hardware Trigger System for Fermilab E866," *Nuclear Instruments and Methods in Physics Research A* 418, 322 (1998).

N. J. Cerf, C. Adami, and P. G. Kwiat, "Optical-Simulation of Quantum Logic," *Physical Review A* 57, R1477 (1998).

R. E. Chrien, N. M. Hoffman, J. D. Colvin, C. J. Keane, O. L. Landen, and B. A. Hammel, "Fusion Neutrons from the Gas-Pusher Interface in Deuterated-Shell Inertial Confinement Fusion Implosions," *Physics of Plasmas* 5, 768 (1998).

B. P. Cluggish, J. R. Danielson, and C. F. Driscoll, "Resonant Particle Heating of an Electron Plasma by Oscillating Sheaths," *Physical Review Letters* 81, 353 (1998).

B. P. Cluggish and C. P. Munson, "Secondary-Electron Enhanced Discharges in Plasma Source Ion-Implantation," *Journal of Applied Physics* 84, 5945 (1998).

B. P. Cluggish and C. P. Munson, "Sheath Overlap during Very Large-Scale Plasma Source Ion-Implantation," *Journal of Applied Physics* 84, 5937 (1998).

J. A. Cobble, A. V. Bessarab, A. V. Kunin, V. A. Tokarev, and S. R. Goldman, "Radiation Temperature-Measurements in Laser-Heated Hohlraums," *Plasma Physics Reports* **24**, 180 (1998).

J. A. Cobble, R. P. Johnson, and R. J. Mason, "Wavelength Scaling of High-Intensity Illumination of an Exploded Foil," *Physics of Plasmas* **5**, 4005 (1998).

S. R. Cook, M. A. Hoffbauer, D. D. Clark, and J. B. Cross, "Measurements of the Reduced Force Coefficients for H_2, N_2, CO, and CO_2 Incident upon a Solar Panel Array Material, SiO_2-Coated Kapton, Kapton, and Z-93-Coated Al," *Physical Review E* **58**, 492 (1998).

M. D. Cooper, V. Armijo, J. K. Black, R. D. Bolton, S. Carius, C. Espinoza, G. Hart, G. E. Hogan, A. Gonzales, M. A. Kroupa, R. E. Mischke, J. Sandoval, S. Schilling, J. Sena, G. Suazo, D. A. Whitehouse, C. A. Wilkinson, K. Stantz, J. J. Szymanski, C. C. Jui, C. A. Gagliardi, R. E. Tribble, X. L. Tu, R. J. Fisk, D. D. Koetke, R. W. Manweiler, P. M. Nord, S. Stanislaus, L. E. Piilonen, and Y. D. Zhang, "Construction and Performance of Mega's Low-Mass, High-Rate Cylindrical MWPCS," *Nuclear Instruments and Methods in Physics Research A* **417**, 24 (1998).

B. E. Crawford, J. D. Bowman, P. P. J. Delheij, C. M. Frankle, M. Iinuma, J. N. Knudson, L. Y. Lowie, A. Masaike, Y. Matsuda, G. E. Mitchell, S. I. Penttilä, H. Postma, N. R. Roberson, S. J. Seestrom, E. I. Sharapov, S. L. Stephenson, Y.-F. Yen, and V. W. Yuan, "Parity Nonconservation in Neutron Resonances in ^{238}U," *Physical Review C* **58**, 1225 (1998).

B. E. Crawford, J. D. Bowman, P. P. J. Delheij, T. Haseyama, J. N. Knudson, L. Y. Lowie, A. Masaike, Y. Matsuda, G. E. Mitchell, S. I. Penttilä, H. Postma, N. R. Roberson, S. J. Seestrom, E. I. Sharapov, S. L. Stephenson, and V. W. Yuan, "Neutron Resonance Spectroscopy of ^{106}Pd and ^{108}Pd from 20 to 2,000 eV," *Physical Review C* **58**, 729 (1998).

H. A. Davis, B. P. Wood, C. P. Munson, L. J. Bitteker, M. A. Nastasi, D. J. Rej, W. J. Waganaar, K. C. Walter, D. M. Coates, and H. M. Schleinitz, "Ion-Beam and Plasma Technology Development for Surface Modification at Los Alamos National Laboratory," *Materials Chemistry and Physics* **54**, 213 (1998).

A. S. Dzurak, B. E. Kane, R. G. Clark, N. E. Lumpkin, J. O'Brien, G. R. Facer, R. P. Starrett, A. Skougarevsky, H. Nakagawa, N. Miura, Y. Enomoto, D. G. Rickel, J. D. Goettee, L. J. Campbell, C. M. Fowler, C. Mielke, J. C. King, W. D. Zerwekh, D. Clark, B. D. Bartram, A. I. Bykov, O. M. Tatsenko, V. V. Platonov, E. E. Mitchell, J. Herrmann, and K. H. Muller, "Transport Measurements of Inplane Critical Fields in $YBa_2Cu_3O_7$-Δ to 300T," *Physical Review B-Condensed Matter* **57**, 14084 (1998).

A. S. Dzurak, B. E. Kane, R. G. Clark, N. E. Lumpkin, J. O'Brien, G. R. Facer, R. P. Starrett, A. Skougarevsky, H. Nakagawa, N. Miura, D. G. Rickel, J. D. Goettee, L. J. Campbell, C. M. Fowler, C. Mielke, J. C. King, W. D. Zerwekh, D. Clark, B. D. Bartram, M. von Ortenberg, F. Herlach, H. Yokoi, A. I. Bykov, O. M. Tatsenko, V. V. Platonov, E. E. Mitchell, J. Hermann, K. H. Muller, K. D. Maranowski, and A. C. Gosard, "Low-Temperature Transport Measurements of Superconductors and Semiconductors in Magnetic-Fields to 800 T," *Physica B* 246, 40 (1998).

M. N. Ericson, M. D. Allen, J. Boissevain, C. L. Britton, M. S. Emery, S. F. Hahn, J. S. Kapustinsky, R. E. Lind, M. S. Musrock, J. Simon-Gillo, D. E. Smith, J. P. Sullivan, H. van Hecke, G. R. Young, and M. C. Smith, "Front-End Module Readout and Control Electronics for the Phenix Multiplicity Vertex Detector," *IEEE Transactions on Nuclear Science* 45, 833 (1998).

M. A. Espy, R. H. Kraus, Jr., E. R. Flynn, and A. Matlashov, "Two Methods for a First Order Hardware Gradiometer using Two High Temperature Superconducting Quantum Interference Devices," *Review of Scientific Instruments* 69, 123 (1998).

C. Evangelista, A. Palano, D. Drijard, N. H. Hamann, R. T. Jones, B. Mouellic, S. Ohlsson, J.-M. Perreau, W. Eyrich, M. Moosburger, S. Pomp, F. Stinzing, H. Fischer, J. Franz, E. Rössle, H. Schmitt, H. Wirth, A. Buzzo, K. Kirsebom, M. Lo Vetere, M. Macri, M. Marinelli, S. Passaggio, M. G. Pia, A. Pozzo, E. Robutti, A. Santroni, P. T. Debevec, R. A. Eisenstein, P. G. Harris, D. W. Hertzog, S. A. Hughes, P. E. Reimer, J. Ritter, R. Geyer, K. Kilian, W. Oelert, K. Röhrich, M. Rook, O. Steinkamp, H. Korsmo, B. Stugu, and T. Johansson, "Study of the Reaction $\bar{p}p \rightarrow \Phi\Phi$ from 1.1 to 2.0 GeV/c," *Physics Review D* 57, 5370 (1998).

J. C. Fernàndez, B. S. Bauer, K. S. Bradley, J. A. Cobble, D. S. Montgomery, R. G. Watt, B. Bezzerides, K. G. Estabrook, R. Focia, S. R. Goldman, D. B. Harris, E. L. Lindman, H. A. Rose, J. Wallace, and B. H. Wilde, "Increased Saturated Levels of Stimulated Brillouin-Scattering of a Laser by Seeding a Plasma with an External Light-Source," *Physical Review Letters* 81, 2252 (1998).

E. Frlez, D. Pocanic, K. A. Assamagan, J. P. Chen, K. J. Keeter, R. M. Marshall, R. C. Minehart, L. C. Smith, G. E. Dodge, S. S. Hanna, B. H. King, and J. N. Knudson, "Differential Cross Sections for Pion Charge Exchange on the Proton at 27.5 MeV," *Physical Review C* 57, 3144 (1998).

Y. Fukuda, T. Hayakawa, E. Ichihara, K. Inoue, K. Ishihara, H. Ishino, Y. Itow, T. Kajita, J. Kameda, S. Kasuga, K. Kobayashi, Y. Kobayashi, Y. Koshio, K. Martens, M. Miura, M. Nakahata, S. Nakayama, A. Okada, M. Oketa, K. Okumura, M. Ota, N. Sakurai, M. Shiozawa, Y. Suzuki,

Y. Takeuchi, Y. Totsuka, S. Yamada, M. Earl, A. Habig, J. T. Hong, E. Kearns, S. B. Kim, M. Masuzawa, M. D. Messier, K. Scholberg, J. L. Stone, L. R. Sulak, C. W. Walter, M. Goldhaber, T. Barszczak, W. Gajewski, P. G. Halverson, J. Hsu, W. R. Kropp, L. R. Price, F. Reines, H. W. Sobel, M. R. Vagins, K. S. Ganezer, W. E. Keig, R. W. Ellsworth, S. Tasaka, J. W. Flanagan, A. Kibayashi, J. G. Learned, S. Matsuno, V. Stenger, D. Takemori, T. Ishii, J. Kanzaki, T. Kobayashi, K. Nakamura, K. Nishikawa, Y. Oyama, A. Sakai, M. Sakuda, O. Sasaki, S. Echigo, M. Kohama, A. T. Suzuki, T. J. Haines, E. Blaufuss, R. Sanford, R. Svoboda, M. L. Chen, Z. Conner, J. A. Goodman, G. W. Sullivan, M. Mori, J. Hill, C. K. Jung, C. Mauger, C. McGrew, E. Sharkey, B. Viren, C. Yanagisawa, W. Doki, T. Ishizuka, Y. Kitaguchi, H. Koga, K. Miyano, H. Okazawa, C. Saji, M. Takahata, A. Kusano, Y. Nagashima, M. Takita, T. Yamaguchi, M. Yoshida, M. Etoh, K. Fujita, A. Hasegawa, T. Hasegawa, S. Hatakeyama, T. Iwamoto, T. Kinebuchi, M. Koga, T. Maruyama, H. Ogawa, A. Suzuki, F. Tsushima, M. Koshiba, M. Nemoto, K. Nishijima, T. Futagami, Y. Hayato, Y. Kanaya, K. Kaneyuki, Y. Watanabe, D. Kielczewska, R. Doyle, J. George, A. Stachyra, L. Wai, J. Wilkes, and K. Young, "Measurements of the Solar-Neutrino Flux from Super-Kamiokande's First 300 Days," *Physical Review Letters* 81, 1158 (1998).

Y. Fukuda, T. Hayakawa, E. Ichihara, K. Inoue, K. Ishihara, H. Ishino, Y. Itow, T. Kajita, J. Kameda, S. Kasuga, K. Kobayashi, Y. Kobayashi, Y. Koshio, K. Martens, M. Miura, M. Nakahata, S. Nakayama, A. Okada, M. Oketa, K. Okumura, M. Ota, N. Sakurai, M. Shiozawa, Y. Suzuki, Y. Takeuchi, Y. Totsuka, S. Yamada, M. Earl, A. Habig, E. Kearns, S. B. Kim, M. D. Messier, K. Scholberg, J. L. Stone, L. R. Sulak, C. W. Walter, M. Goldhaber, T. Barszczak, W. Gajewski, P. G. Halverson, J. Hsu, W. R. Kropp, L. R. Price, F. Reines, H. W. Sobel, M. R. Vagins, K. S. Ganezer, W. E. Keig, R. W. Ellsworth, S. Tasaka, J. W. Flanagan, A. Kibayashi, J. G. Learned, S. Matsuno, V. Stenger, D. Takemori, T. Ishii, J. Kanzaki, T. Kobayashi, K. Nakamura, K. Nishikawa, Y. Oyama, A. Sakai, M. Sakuda, O. Sasaki, S. Echigo, M. Kohama, A. T. Suzuki, T. J. Haines, E. Blaufuss, R. Sanford, R. Svoboda, M. L. Chen, Z. Conner, J. A. Goodman, G. W. Sullivan, M. Mori, J. Hill, C. K. Jung, C. Mauger, C. McGrew, E. Sharkey, B. Viren, C. Yanagisawa, W. Doki, T. Ishizuka, Y. Kitaguchi, H. Koga, K. Miyano, H. Okazawa, C. Saji, M. Takahata, A. Kusano, Y. Nagashima, M. Takita, T. Yamaguchi, M. Yoshida, M. Etoh, K. Fujita, A. Hasegawa, T. Hasegawa, S. Hatakeyama, T. Iwamoto, T. Kinebuchi, M. Koga, T. Maruyama, H. Ogawa, A. Suzuki, F. Tsushima, M. Koshiba, M. Nemoto, K. Nishijima, T. Futagami, Y. Hayato, Y. Kanaya, K. Kaneyuki, Y. Watanabe, D. Kielczewska, R. Doyle, J. George, A. Stachyra, L. Wai, J. Wilkes, and K. Young, "Study of the Atmospheric Neutrino Flux in the Multi-GeV Energy-Range," *Physics Letters B* 436, 33 (1998).

Y. Fukuda, T. Hayakawa, E. Ichihara, K. Inoue, K. Ishihara, H. Ishino, Y. Itow, T. Kajita, J. Kameda, S. Kasuga, K. Kobayashi, Y. Kobayashi, Y. Koshio, M. Miura, M. Nakahata, S. Nakayama, A. Okada, K. Okumura, N. Sakurai, M. Shiozawa, Y. Suzuki, Y. Takeuchi, Y. Totsuka, S. Yamada, M. Earl, A. Habig, E. Kearns, M. D. Messier, K. Scholberg, J. L. Stone,

L. R. Sulak, C. W. Walter, M. Goldhaber, T. Barszczxak, D. Casper, W. Gajewski, P. G. Halverson, J. Hsu, W. R. Kropp, L. R. Price, F. Reines, M. Smy, H. W. Sobel, M. R. Vagins, K. S. Ganezer, W. E. Keig, R. W. Ellsworth, S. Tasaka, J. W. Flanagan, A. Kibayashi, J. G. Learned, S. Matsuno, V. J. Stenger, D. Takemori, T. Ishii, J. Kanzaki, T. Kobayashi, S. Mine, K. Nakamura, K. Nishikawa, Y. Oyama, A. Sakai, M. Sakuda, O. Sasaki, S. Echigo, M. Kohama, A. T. Suzuki, T. J. Haines, E. Blaufuss, B. K. Kim, R. Sanford, R. Svoboda, M. L. Chen, Z. Conner, J. A. Goodman, G. W. Sullivan, J. Hill, C. K. Jung, K. Martens, C. Mauger, C. McGrew, E. Sharkey, B. Viren, C. Yanagisawa, W. Doki, K. Miyano, H. Okazawa, C. Saji, M. Takahata, Y. Nagashima, M. Takita, T. Yamaguchi, M. Yoshida, S. B. Kim, M. Etoh, K. Fujita, A. Hasegawa, T. Hasegawa, S. Hatakeyama, T. Iwamoto, M. Koga, T. Maruyama, H. Ogawa, J. Shirai, A. Suzuki, F. Tsushima, M. Koshiba, M. Nemoto, K. Nishijima, T. Futagami, Y. Hayato, Y. Kanaya, K. Kaneyuki, Y. Watanabe, D. Kielczewska, R. A. Doyle, J. S. George, A. L. Stachyra, L. L. Wai, R. J. Wilkes, and K. K. Young, "Evidence for Oscillation of Atmospheric Neutrinos," *Physical Review Letters* 81, 1562 (1998).

R. Guckert, X. Zhao, S. G. Crane, A. Hime, W. A. Taylor, D. Tupa, D. J. Vieira, and H. Wollnik, "Magnetooptical Trapping of Radioactive ^{82}Rb Atoms," *Physical Review A* 58, R1637 (1998).

D. G. Haase, C. D. Keith, C. R. Gould, P. R. Huffman, N. R. Roberson, M. L. Seely, W. Tornow, and W. S. Wilburn, "The Scattering of Polarized Neutrons from Statically Polarized Solid ^{3}He," *Nuclear Instruments and Methods in Physics Research A* 402, 341 (1998).

A. H. Hamdi, X. Qiu, G. W. Malaczynski, A. A. Elmoursi, S. Simko, M. C. Militello, M. P. Balogh, B. P. Wood, K. C. Walter, and M. A. Nastasi, "Microstructure Analysis of Plasma Immersion Ion-Implanted Diamond-Like Carbon Coatings," *Surface and Coatings Technology* 104, 395 (1998).

E. A. Hawker, T. C. Awes, M. E. Beddo, C. N. Brown, J. D. Bush, T. A. Carey, T. H. Chang, W. E. Cooper, C. A. Gagliardi, G. T. Garvey, D. F. Geesaman, X. C. He, L. D. Isenhower, S. B. Kaufman, D. M. Kaplan, P. N. Kirk, D. D. Koetke, G. Kyle, D. M. Lee, W. M. Lee, M. J. Leitch, N. Makins, P. L. McGaughey, J. M. Moss, B. A Mueller, P. M. Nord, B. K. Park, V. Papavassiliou, J.-C. Peng, G. Petitt, P. E. Reimer, M. E. Sadler, J. Selden, P. W. Stankus, W. E. Sondheim, T. N. Thompson, R. S. Towell, R. E. Tribble, M. A. Vasiliev, Y. C. Wang, Z. F. Wang, J. C. Webb, J. L. Willis, D. K. Wise, and G. R. Young, "Measurement of the Light Antiquark Flavor Asymmetry in the Nucleon Sea," *Physical Review Letters* 80, 3715 (1998).

W.-C. Hsi, K. Kwiatkowski, G. Wang, D. S. Bracken, E. Cornell, D. S. Ginger, V. E. Viola, N. R. Yoder, R. G. Korteling, R. Gimeno-Nogues, E. Ramakrishnan, D. Rowland, S. J. Yennello, R. Huang, W. G. Lynch, M. B. Tsang, H. Xi, H. Breuer, K. B. Morley, S. Gushue,

L. P. Remsberg, W. A. Friedman, and A. Botvina, "Sideways-Peaked Angular-Distributions in Hadron-Induced-Multifragmentation: Shock-Waves, Geometry, or Kinematics," *Physical Review C* 48, R13 (1998).

M. C. Huang, J. Aine, S. Supek, E. Best, D. Ranken, and E. R. Flynn, "Multi-Start Downhill Simplex Method for Spatiotemporal Source Localization in Magnetoencephalography Evoked Potentials," *Electroencephalography and Clinical Neurophysiology* 108, 32 (1998).

R. J. Hughes, "Cryptography, Quantum Computation and Trapped Ions," *Philosophical Transactions of the Royal Society of London Series A* 356, 1853 (1998).

R. J. Hughes and D. F. V. James, "Prospects for Quantum Computation with Trapped Ions," *Fortschritte der Physik* 46, 759 (1998).

R. J. Hughes, D. F. V. James, J. J. Gomez, M. S. Gulley, M. H. Holzscheiter, P. G. Kwiat, S. K. Lamoreaux, C. G. Peterson, V. D. Sandberg, M. M. Schauer, C. M. Simmons, C. E. Thorburn, D. Tupa, P. Z. Wang, and A. G. White, "The Los Alamos Trapped Ion Quantum Computer Experiment," *Fortschritte Der Physik-Progress of Physics* 46, 329 (1998).

M. B. Johnson and V. M. Belyaev, "Deep-Inelastic Scattering and the Pion Light-Cone Wave-Function," *Acta Physica Polonica B* 29, 2527 (1998).

M. B. Johnson and L. S. Kisslinger, "Hadronic Couplings via QCD Sum Rules using Three-Point Functions: Vacuum Susceptibilities," *Physical Review D* 57, 2847 (1998).

J. S. Kapustinsky, J. Boissevain, E. Bosze, D. Clark, D. Jaffe, S. Y. Kim, L. Marek, J. Simon-Gillo, J. Sullivan, H. van Hecke, and G. Xu, "A Double-Metal Silicon Pad Design for the PHENIX Multiplicity/Vertex Detector," *Nuclear Instruments and Methods in Physics Research A* 409, 173 (1998).

A. A. Khan, T. Bhattacharya, S. Collins, C. T. H. Davies, R. Gupta, C. Morningstar, J. Shigemitsu, and J. Sloan, "B-Meson Decay Constants from NRQCD," *Physics Letters B* 427, 132 (1998).

J. A. Koch, O. L. Landen, T. W. Barbee, P. Celliers, L. B. Dasilva, S. G. Glendinning, B. A. Hammel, D. H. Kalantar, C. Brown, J. Seely, G. R. Bennett, and W. Hsing, "High-Energy X-Ray Microscopy Techniques for Laser-Fusion Plasma Research at the National Ignition Facility," *Applied Optics* 37, 1784 (1998).

J. A. Koch, O. L. Landen, B. A. Hammel, J. Seely, T. W. Barbee, G. Bennett, C. Brown, P. Celliers, L. B. Dasilva, S. G. Glendinning, W. Hsing, and D. H. Kalantar, "High-Energy X-Ray Microscopy of Laser-

Fusion Plasmas at the National Ignition Facility," *Plasma Physics Reports* 24, 177 (1998).

T. Kozlowski, E. Desmond, J. Haggerty, H.-J. Kehayias, M. Purschke, and C. Witzig, "Analysis, Design, and Implementation of PHENIX Online Computing Systems Software using Shlaer-Mellor Object-Oriented Analysis and Recursive-Design," *Computer Physics Communications* 110, 164 (1998).

M. Krammer, W. Adam, C. Bauer, E. Berdermann, F. Bogani, E. Borchi, M. Bruzzi, C. Colledani, J. Conway, W. Dabrowski, P. Delpierre, A. Deneuville, W. Dulinski, B. Vaneijk, A. Fallou, D. Fish, F. Foulon, M. Friedl, K. K. Gan, E. Gheeraert, E. Grigoriev, G. Hallewell, R. Hallwilton, S. Han, F. Hartjes, J. Hrubec, D. Husson, H. Kagan, D. Kania, J. Kaplon, R. Kass, K. T. Knöpfle, P. F. Manfredi, D. Meier, M. Mishina, F. Lenormand, L. S. Pan, H. Pernegger, M. Pernicka, V. Re, G. L. Riester, S. Roe, D. Roff, A. Rudge, S. Schnetzer, S. Sciortino, V. Speziali, H. Stelzer, R. Stone, R. J. Tapper, R. Tesarek, G. B. Thomson, M. Trawick, W. Trischuk, R. Turchetta, A. M. Walsh, R. Wedenig, P. Weilhammer, H. Ziock, and M. Zoeller, "Status of Diamond Particle Detectors," *Nuclear Instruments and Methods in Physics Research Section A* 418, 196 (1998).

W. L. Kruer, B. B. Afeyan, A. E. Chou, R. K. Kirkwood, D. S. Montgomery, P. W. Rambo, and S. C. Wilks, "Interplay Between Laser-Plasma Instabilities," *Physica Scripta* T75, 7 (1998).

P. G. Kwiat, "Experimental and Theoretical Progress in Interaction-Free Measurements," *Physica Scripta* T76, 115 (1998).

P. G. Kwiat and H. Weinfurter, "Embedded Bell-State Analysis," *Physical Review A* 58, R2623 (1998).

K. Kwiatkowski, D. S. Bracken, E. Renshaw Foxford, K. B. Morley, E. C. Pollacco, C. Volant, R. G. Korteling, W. A. Friedman, and A. S. Botvina, "Heating Nuclear Matter with GeV ^{3}He Beams," *Physics Letters B* 423, 21 (1998).

R. M. Leahy, J. C. Mosher, M. E. Spencer, M. X. Huang, and J. D. Lewine, "A Study of Dipole Localization Accuracy for MEG and EEG using a Human Skull Phantom," *Electroencephalography and Clinical Neurophysiology* 107, 159 (1998).

D. H. Lee, X. M. He, K. C. Walter, M. Nastasi, J. R. Tesmer, M. Tuszewski, and D. R. Tallant, "Diamond-Like Carbon Deposition on Silicon using Radiofrequency Inductive Plasma of Ar and C_2H_2 Gas-Mixture in Plasma Immersion Ion Deposition," *Applied Physics Letters* 73, 2423 (1998).

S. A. Long, B. M. Spicer, K. J. Raywood, R. Abegg, W. P. Alford, A. Celler, D. Frekers, P. E. Green, O. Häusser, R. L. Helmer, R. S. Henderson, K. H. Hicks, K. P. Jackson, R. G. Jeppesen, N. S. P. King, C. A. Miller, M. A. Moinester, V. C. Officer, G. G. Shute, A. Trudel, M. C. Vetterli, A. I. Yavin, and S. Yen, "Spin-Isovector Giant-Resonances Induced by (N,P) Reactions on Heavy-Nuclei," *Physical Review C* 57, 3191 (1998).

G. R. Magelssen, N. D. Delamater, E. L. Lindman, and A. A. Hauer, "Measurements of Early Time Radiation Asymmetry in Vacuum and Methane-Filled Hohlraums with the Reemission Ball Technique," *Physical Review E* 57, 4663 (1998).

F. J. Marshall, M. M. Allen, J. P. Knauer, J. A. Oertel, and T. Archuleta, "A High-Resolution X-Ray Microscope for Laser-Driven Planar-Foil Experiments," *Physics of Plasmas* 5, 1118 (1998).

R. J. Mason, R. A. Kopp, H. X. Vu, D. C. Wilson, S. R. Goldman, R. G. Watt, M. Dunne, and O. Willi, "Computational Study of Laser Imprint Mitigation in Foam-Buffered Inertial Confinement Fusion Targets," *Physics of Plasmas* 5, 211 (1998).

A. O. Mateos, D. Androic, G. Backenstoss, D. Bosnar, H. Breuer, H. Dobbeling, T. Dooling, M. Furic, P. A. M. Gram, N. K. Gregory, A. Hoffart, Q. Ingram, A. Klein, K. Koch, J. Kohler, B. Kotlinski, M. Kroedel, G. Kyle, A. Lehmann, K. Michaelian, T. Petkovic, M. Planinic, R. P. Redwine, D. Rowntree, U. Sennhauser, N. Simicevic, R. Trezeciak, H. Ullrich, M. Wang, M. H. Wang, H. J. Weyer, M. Wildi, and K. E. Wilson, "Total and Partial Pion Absorption Cross-Sections on ^{4}He in the Δ-Resonance Region," *Physical Review C* 58, 942 (1998).

G. B. Mills, "Neutrino Oscillation Resultsfrom LSND," *Nuclear Physics B* 66, 382 (1998).

D. S. Montgomery, B. B. Afeyan, J. A. Cobble, J. C. Fernàndez, M. D. Wilke, S. H. Glenzer, R. K. Kirkwood, B. J. MacGowan, J. D. Moody, E. L. Lindman, D. H. Munro, B. H. Wilde, H. A. Rose, D. F. DuBois, B. Bezzerides, and H. X. Vu, "Evidence of Plasma Fluctuations and their Effect on the Growth of Stimulated Brillouin and Stimulated Raman-Scattering in Laser Plasmas," *Physics of Plasmas* 5, 1973 (1998).

C. L. Morris, J. D. Zumbro, J. A. McGill, S. J. Seestrom, R. M. Whitton, C. M. Reidel, A. L. Williams, M. R. Braunstein, M. D. Kohler, B. J. Kriss, S. Hoibraten, J. Ouyang, R. J. Peterson, and J. E. Wise, "Evidence for Δ^- Components in Nuclei," *Physics Letters B* 419, 25 (1998).

J. C. Mosher and R. M. Leahy, "Recursive Music: A Framework for EEG and MEG Source Localization," *IEEE Transactions On Biomedical Engineering* 45, 1342 (1998).

T. J. Murphy, J. A. Oertel, T. N. Archuleta, C. W. Barnes, R. J. Bartlett, R. R. Berggren, S. B. Boggs, S. E. Caldwell, R. E. Chrien, J. A. Cobble, B. H. Failor, J. R. Faulkner, J. C. Fernández, A. A. Hauer, G. Idzorek, J. L. Jimerson, K. A. Klare, G. A. Kyrala, R. D. Little, L. Looney, D. Montgomery, R. A. Schmell, T. J. Sedillo, W. K. Thorn, R. G. Watt, and M. D. Wilke, “Recent Diagnostic Development for Inertial Confinement Fusion Research at Los Alamos National Laboratory,” *Plasma Physics Reports* 24, 123 (1998).

T. J. Murphy, J. M. Wallace, N. D. Delamater, C. W. Barnes, P. Gobby, A. A. Hauer, E. L. Lindman, G. Magelssen, J. B. Moore, J. A. Oertel, R. Watt, O. L. Landen, P. Amendt, M. Cable, C. Decker, B. A. Hammel, J. A. Koch, L. J. Suter, R. E. Turner, R. J. Wallace, F. J. Marshall, D. Bradley, R. S. Craxton, R. Keck, J. P. Knauer, R. Kremens, and J. D. Schnittman, “Experiments with Multiple-Beam Cones on the Omega-Laser Facility,” *Physical Review Letters* 81, 108 (1998).

T. J. Murphy, J. M. Wallace, N. D. Delamater, C. W. Barnes, P. Gobby, A. A. Hauer, E. L. Lindman, G. Magelssen, J. B. Moore, J. A. Oertel, R. Watt, O. L. Landen, P. Amendt, M. Cable, C. Decker, B. A. Hammel, J. A. Koch, L. J.Suter, R. E. Turner, R. J. Wallace, F. J. Marshall, D. Bradley, R. S. Craxton, R. Keek, J. P. Knauer, R. Kremens, and J. D. Schnittman, “Indirect Drive Experiments utilizing Multiple-Beam Cones in Cylindrical Hohlraums on Omega,” *Physics of Plasmas* 5, 1960 (1998).

G. A. Navratil, C. Cates, M. E. Mauel, D. Maurer, D. Nadle, E. Taylor, Q. Xiao, W. A. Reass, and G. A. Wurden, “Active Control of 2/1 Magnetic Islands in a Tokamak,” *Physics of Plasmas* 5, 1855 (1998).

G. U. Nienhaus, K. Chu, and K. Jesse, “Structural Heterogeneity and Ligand-Binding in Carbonmonoxy Myoglobin Crystals at Cryogenic Temperatures,” *Biochemistry* 37, 6819 (1998).

E. A. Pasyuk, C. L. Morris, J. L. Ullmann, J. D. Zumbro, L. W. Kwok, J. L. Matthews, and Y. Tan, “A Search For Δ^- and Δ^{++} Wave-Function Components in Light-Nuclei using the (π^+,$\pi^- p$) and (N,2p) Reactions,” *Acta Physica Polonica B* 29, 2335 (1998).

T. S. Peat, J. Newman, G. S. Waldo, J. Berendzen, and T. C. Terwilliger, “Structure of Translation Initiation-Factor 5a from Pyrobaculum-Aerophilum at 1.75 Angstrom Resolution,” *Structure* 6, 1207 (1998).

J.-C. Peng, G. T. Garvey, T. C. Awes, M. E. Beddo, M. L. Brooks, C. N. Brown, J. D. Bush, T. A. Carey, T. H. Chang, W. E. Cooper, C. A. Gagliardi, D. F. Geesaman, E. A. Hawker, X. C. He, L. D. Isenhower, S. B. Kaufman, D. M. Kaplan, P. N. Kirk, D. D. Koetke, G. Kyle, D. M. Lee, W. M. Lee, M. J. Leitch, N. Makins, P. L. McGaughey, J. M. Moss, B. A. Mueller, P. M. Nord, B. K. Park, V. Papavassiliou, G. Petitt, P. E. Reimer, M. E. Sadler, P. W. Stankus, W. E. Sondheim,

T. N. Thompson, R. S. Towell, R. E. Tribble, M. A. Vasiliev, Y. C. Wang, Z. F. Wang, J. C. Webb, J. L. Willis, D. K. Wise, and G. R. Young, "$\bar{d}/\bar{u}$ Asymmetry and the Origin of the Nucleon Sea," *Physical Review D* 58, 092004 (1998).

V. V. Platonov, O. M. Tatsenko, A. I. Bykov, M. I. Dolotenko, J. C. Solem, C. M. Fowler, J. D. Goettee, D. Rickel, L. J. Campbell, L. Veeser, M. Sheppard, A. H. Lacerda, J. C. King, P. J. Rodriguez, D. E. Bartram, R. G. Clark, B. E. Kane, A. S. Dzurak, G. R. Facer, N. Miura, T. Takamasu, H. Nakagawa, H. Yokoi, J. S. Brooks, L. W. Engel, L. Pfeiffer, K. W. West, A. W. Maverick, L. G. Butler, W. Lewis, C. H. Gallegos, and B. Marshall, "The Faraday-Effect in $Cd_{0.57}Mn_{0.43}Te$ in High Magnetic-Field," *Physica B* 246, 319 (1998).

D. C. Rislove, C. E. M. Strauss, H. C. Bryant, M. S. Gulley, D. J. Funk, X. M. Zhao, and W. A. Miller, "Characterization of the D^-1(E) Autodetaching Resonance in H^- and D," *Physical Review A* 58, 1889 (1998).

J. A. R. Samson, W. C. Stolte, Z. X. He, J. N. Cutler, Y. Lu, and R. J. Bartlett, "Double Photoionization of Helium," *Physical Review A* 57, 1906 (1998).

K. F. Schoenberg, R. A. Gerwin, R. W. Moses, J. T. Scheuer, and H. P. Wagner, "Magnetohydrodynamic Flow Physics of Magnetically Nozzled Plasma Accelerators with Applications to Advanced Manufacturing," *Physics of Plasmas* 5, 2090 (1998).

S. J. Seestrom, J. D. Bowman, B. E. Crawford, P. P. J. Delheij, C. M. Frankle, C. R. Gould, D. G. Haase, M. Iinuma, J. N. Knudson, P. E. Koehler, L. Y. Lowie, A. Masaike, Y. Masuda, Y. Matsuda, G. E. Mitchell, S. I. Penttilä, Y. P. Popov, H. Postma, N. R. Roberson, E. I. Sharapov, H. M. Shimizu, D. A. Smith, S. L. Stephenson, Y.-F. Yen, and V. W. Yuan, "Parity Nonconservation in Neutron-Capture on Cd-113," *Physical Review C* 58, 2977 (1998).

G. S. Selwyn, C. A. Weiss, F. Sequeda, and C. Huang, "In-Situ Analysis of Particle Contamination in Magnetron Sputtering Processes," *Thin Solid Films* 317, 85 (1998).

M. Shiozawa, B. Viren, Y. Fukuda, T. Hayakawa, E. Ichihara, K. Inoue, K. Ishihara, H. Ishino, Y. Itow, T. Kajita, J. Kameda, S. Kasuga, K. Kobayashi, Y. Kobayashi, Y. Koshio, M. Miura, M. Nakahata, S. Nakayama, A. Okada, M. Oketa, K. Okumura, M. Ota, N. Sakurai, Y. Suzuki, Y. Takeuchi, Y. Totsuka, S. Yamada, M. Earl, A. Habig, E. Kearns, M. D. Messier, K. Scholberg, J. L. Stone, L. R. Sulak, C. W. Walter, M. Goldhaber, T. Barszczak, W. Gajewski, P. G. Halverson, J. Hsu, W. R. Kropp, L. R. Price, F. Reines, H. W. Sobel, M. R. Vagins, K. S. Ganezer, W. E. Keig, R. W. Ellsworth, S. Tasaka, J. W. Flanagan, A. Kibayashi, J. G. Learned, S. Matsuno, V. Stenger, D. Takemori, T. Ishii,

J. Kanzaki, T. Kobayashi, K. Nakamura, K. Nishikawa, Y. Oyama, A. Sakai, M. Sakuda, O. Sasaki, S. Echigo, M. Kohama, A. T. Suzuki, T. J. Haines, E. Blaufuss, R. Sanford, R. Svoboda, M. L. Chen, Z. Conner, J. A. Goodman, G. W. Sullivan, M. Mori, J. Hill, C. K. Jung, K. Martens, C. Mauger, C. McGrew, E. Sharkey, C. Yanagisawa, W. Doki, T. Ishizuka, Y. Kitaguchi, H. Koga, K. Miyano, H. Okazawa, C. Saji, M. Takahata, A. Kusano, Y. Nagashima, M. Takita, T. Yamaguchi, M. Yoshida, S. B. Kim, M. Etoh, K. Fujita, A. Hasegawa, T. Hasegawa, S. Hatakeyama, T. Iwamoto, T. Kinebuchi, M. Koga, T. Maruyama, H. Ogawa, A. Suzuki, F. Tsushima, M. Koshiba, M. Nemoto, K. Nishijima, T. Futagami, Y. Hayato, Y. Kanaya, K. Kaneyuki, Y. Watanabe, D. Kielczewska, R. Doyle, J. George, A. Stachyra, L. Wai, J. Wilkes, and K. Young, "Search for Proton Decay via $p^- e^+ \pi^0$ in a Large Water Cherenkov Detector," *Physical Review Letters* 81, 3319 (1998).

P. A. Souder, P. L. Bogorad, E. J. Brash, G. D. Cates, W. J. Cummings, A. Gorelov, M. D. Hasinoff, O. Häusser, K. Hicks, R. Holmes, J. C. Huang, K. S. Kumar, B. Larson, W. Lorenzon, J. McCracken, P. Michaux, H. Middleton, E. Saettler, D. Siegel, D. Tupa, X. Wang, and A. Young, "Laser Polarized Muonic ^{3}He and Spin-Dependent μ^- Capture," *Nuclear Instruments and Methods in Physics Research A* 402, 311 (1998).

P. Staples and K. Morley, "Neutron-Induced Fission Cross-Section Ratios for Pu-239, Pu-240, Pu-242, and Pu-244 Relative to U-235 from 0.5 to 400 MeV," *Nuclear Science and Engineering* 129, 149 (1998).

S. L. Stephenson, J. D. Bowman, B. E. Crawford, P. P. J. Delheij, C. M. Frankle, M. Iinuma, J. N. Knudson, L. Y. Lowie, A. Masaike, Y. Matsuda, G. E. Mitchell, S. I. Penttilä, H. Postma, N. R. Roberson, S. J. Seestrom, E. I. Sharapov, Y.-F. Yen, and V. W. Yuan, "Parity Nonconservation in Neutron Resonances in Th-232," *Physical Review C* 58, 1236 (1998).

T. C. Terwilliger, G. Waldo, T. S. Peat, J. M. Newman, K. Chu, and J. Berendzen, "Class-Directed Structure Determination: Foundation for a Protein-Structure Initiative," *Protein Science* 7, 1851 (1998).

W. Tornow, T. S. Carman, Q. Chen, W. R. Gibbs, B. F. Gibson, D. E. G. Trotter, C. R. Howell, A. H. Hussein, G. Mertens, C. F. Moore, C. Morris, A. Obst, E. Pasyuk, C. D. Roper, F. Salinas, D. Schmidt, H. R. Setze, I. Slaus, S. Sterbenz, H. Tang, R. L. Walter, C. R.Whiteley, H. Witala, and Z. Zhou, "Scattering Length Measurements from Radiative Pion Capture and Neutron-Deuteron Breakup," *Nuclear Physics A* 631, C421 (1998).

Y. Tosaka, S. Satoh, T. Itakura, H. Ehara, T. Ueda, G. A. Woffinden, and S. A. Wender, "Measurement and Analysis of Neutron-Induced Soft Errors in Sub-Half-Micron CMOS Circuits," *IEEE Transactions on Electron Devices* 45, 1453 (1998).

M. Tuszewski, “Particle and Heat-Transport in a Low-Frequency Inductively-Coupled Plasma,” *Physics Of Plasmas* 5, 1198 (1998).

A. M. Urnov, J. Dubau, A. Ya Faenov, T. A. Pikuz, I. Y. Skobelev, J. Abdallah, R. E. H. Clark, J. Cohen, R. P. Johnson, G. A. Kyrala, M. D. Wilke, and A. L. Osterheld, “X-Ray-Spectra of Multiply-Charged Hollow Ions in the Emission from a Femtosecond Laser-Plasma,” *JETP Letters* 67, 489 (1998).

J. R. Walston, C. D. Keith, C. R. Gould, D. G. Haase, B. W. Raichle, M. L. Seely, W. Tornow, W. S. Wilburn, G. W. Hoffmann, and S. I. Penttilä, “Polarization Transfer in the ^{3}H($\vec{p},\vec{n}$)^{3}He Reaction and the 0^- Level in ^{4}He,” *Physical Review C* 58, 1314 (1998).

K. C. Walter, M. Nastasi, N. P. Baker, C. P. Munson, W. K. Scarborough, J. T. Scheuer, B. P. Wood, J. R. Conrad, K. Sridharan, S. Malik, and R. A. Bruen, “Advances in PSII Techniques for Surface Modification,” *Surface and Coatings Technology* 104, 205 (1998).

G. Wang, K. Kwiatkowski, D. S. Bracken. E. Foxford, W.-C. Hsi, R. G. Korteling, R. Legrain, K. B. Morley, E. C. Pollacco, V. E. Viola, and C. Volant, “Time Scale for Emission of Soft Ejectiles in the Disassembly of Hot Nuclei,” *Physics Review C* 57, R2786 (1998).

R. G. Watt, J. Duke, C. J. Fontes, P. L. Gobby, R. V. Hollis, R. A. Kopp, R. J. Mason, D. C. Wilson, C. P. Verdon, T. R. Boehly, J. P. Knauer, D. D. Meyerhofer, V. Smalyuk, R. P. J. Town, A. Iwase, and O. Willi, “Laser Imprint Reduction using a Low-Density Foam Buffer as a Thermal Smoothing Layer at 351-nm Wavelength,” *Physical Review Letters* 81, 4644 (1998).

A. G. White, J. R. Mitchell, O. Nairz, and P. G. Kwiat, “Interaction-Free Imaging,” *Physical Review A* 58, 605 (1998).

W. S. Wilburn and J. D. Bowman, “Consistency of Parity-Violating Pion-Nucleon Couplings Extracted from Measurements in F-18 and Cs-133,” *Physical Review* C 57, 3425 (1998).

W. S. Wilburn, C. R. Gould, G. M. Hale, P. R. Huffman, C. D. Keith, N. R. Roberson, and W. Tornow, “Measurements at Low Energies of the Polarization-Transfer Coefficient K-Y(Y’) for the Reaction ^{3}H($\vec{p},\vec{n}$)^{3}He at 0°,” *Few-Body Systems* 24, 27 (1998).

D. C. Wilson, P. A. Bradley, N. M. Hoffman, F. J. Swenson, D. P. Smitherman, R. E. Chrien, R. W. Margevicius, D. J. Thoma, L. R. Foreman, J. K. Hoffer, S. R. Goldman, S. E. Caldwell, T. R. Dittrich, S. W. Haan, M. M. Marinak, S. M. Pollaine, and J. J. Sanchez, “The Development and Advantages of Beryllium Capsules for the National Ignition Facility,” *Physics of Plasmas* 5, 1953 (1998).

B. P. Wood, A. J. Perry, L. J. Bitteker, and W. J. Waganaar, "Cratering Behavior in Single-Crystalline and Polycrystalline Copper Irradiated by an Intense Pulsed Ion-Beam," *Surface and Coatings Technology* **109**, 171 (1998).

1997 Conferences

J. Abdallah, Jr., M. D. Wilke, G. A. Kyrala, R. E. H. Clark, A. Ya Faenov, and T. A. Faenov, "Hot Electron Effects on the Satellite Spectrum of Laser Produced Plasmas," 27th Annual Anomalous Absorption Conference (Vancouver, Canada, May–June 1997).

K. H. Adams, K. R. Alrick, J. F. Amann, J. G. Boissevain, M. L. Crow, S. B. Cushing, J. C. Eddleman, C. J. Espinoza, T. T. Fife, R. A. Gallegos, J. J. Gomez, T. J. Gorman, N. T. Gray, G. E. Hogan, V. H. Holmes, Jr., S. A. Jaramillo, N. S. P. King, J. N. Knudson, R. K. London, R. P. Lopez, J. B. McClelland, F. E. Merrill, K. B. Morley, C. L. Morris, C. T. Mottershead, K. H. Mueller, D. M. Numkena, P. Pazuchanics, C. Pillai, C.-M. Riedel, J. S. Sarracino, H. L. Stacy, B. E. Takala, H. E. Tucker, G. J. Yates, H.-J. Ziock, J. D. Zumbro, E. Ables, M. E. Aufderheide, P. D. Barnes, R. M. Bionta, D. H. Fujino, E. P. Hartouni, S. S. Park, and R. Soltz, "Proton Radiography Concept," Semiconductor Tracking Detectors (Melbourne, Australia, December 1997).

C. J. Aine, H. W. Chen, D. Ranken, J. Mosher, E. Best, J. George, J. Lewine, and K. Paulson, "An Examination of Chromatic/Achromatic Stimuli Presented to Central/Peripheral Visual Fields: An MEG Study," 3rd International Conference on Functional Mapping of the Human Brain (Copenhagen, Denmark, May 1997), abstract in *Neuroimage* **5**, 153 (1997).

C. J. Aine, D. Ranken, M. Huang, J. C. Mosher, E. Best, J. George, and J. Lewine, "Retinotopy of Cingulate Cortex? An MEG Study," 3rd International Conference on Functional Mapping of the Human Brain (Copenhagen, Denmark, May 1997), abstract in *Neuroimage* **5**, 152 (1997).

J. F. Amann, L. G. Atencio, C. J. Espinoza, J. J. Gomez, G. W. Hart, R. E. Hill, G. E. Hogan, S. A. Jaramillo, N. S. P. King, L. J. Marek, J. B. McClelland, K. B. Morley, C. L. Morris, C. T. Mottershead, K. H. Mueller, P. Pazuchanics, J. S. Sarracino, G. J. Yates, H.-J. Ziock, J. D. Zumbro, A. Saunders, J. M. O'Donnell, E. P. Hartouni, R. Prigl, and E. T. Schwaner, "High-Energy Test of Proton Radiography Concepts," 11th Biennial Nuclear Explosives Design Physics Conference (Livermore, California, October 1997).

M. Amman, J. F. Beche, E. Beuville, V. Douence, L. Fabris, F. Goulding, N. Madden, J. Millaud, B. Turko, J. Walton, J. Zaninovich, K. R. Alrick, R. A. Gallegos, J. E. Galyardt, N. T. Gray, G. E. Hogan, V. H. Holmes, Jr., S. A. Jaramillo, N. S. P. King, T. E. McDonald, K. B. Morley, C. L. Morris, D. M. Numkena, P. Pazuchanics, C.-M. Riedel, J. S. Sarracino, G. J. Yates, H.-J. Ziock, and J. D. Zumbro, "Detector Development for Dynamic Proton Radiography," Semiconductor Tracking Detectors (Melbourne, Australia, December 1997).

M. Amman, J. F. Beche, E. Beuville, V. Douence, L. Fabris, F. Goulding, N. Madden, J. Millaud, B. Turko, J. Walton, J. Zaninovich, R. A. Gallegos, J. E. Galyardt, T. E. McDonald, N. S. P. King, G. J. Yates, and H. Ziock, "Detector Systems for Proton Radiography," Front-End Electrons for High-Resolution Tracking Detectors (Taos, New Mexico, November 1997).

D. E. Archer, J. A. Becker, L. A. Bernstein, W. Younes, D. M. Drake, G. D. Johns, and R. O. Nelson, "Capabilities of GEANIE at LANSCE/WNR: Spectroscopy of 238U," American Physical Society/AAPT Meeting (Washington, D.C., April 1997).

W. L. Atchison, R. J. Faehl, D. V. Morgan, and R. E. Reinovsky, "Examination of Instability Growth in Solid Liner Surfaces using Comparison of Two-Dimensional MHD Calculations and Measured Data," Dense Z-Pinches (Vancouver, Canada, May 1997).

A. Babushkin, W. Bittle, S. A. Letzring, A. Okishev, M. D. Skeldon, W. Seka, C. R. Pollock, and W. R. Bosenberg, "Stable, Reproducible, and Externally Synchronizable Regenerative Amplifier for Shaped Optical Pulses for the OMEGA Laser System," Topical Meeting on Advanced Solid State Lasers (Orlando, Florida, January 1997), *OSA Trends in Optics and Photonics Series* **10**, 106 (1997).

A. Babushkin, W. Seka, W. Bittle, S. A. Letzring, and M. D. Skeldon, "Ultrastable, Reliable Flash-Lamp Pumped and Negative Feedback Controlled Regenerative Amplifier for the OMEGA Laser Pulse-Shaping System," Conference on Lasers and Electro-Optics (CLEO '97) (Baltimore, Maryland, May 1997), *CLEO '97 Technical Digest Series* (1997).

A. Babushkin, W. Seka, S. A. Letzring, W. Bittle, C. T. Cotton, M. Labuzeta, M. Miller, and R. G. Rhodes, "Fiducial Laser for the OMEGA Laser System," Conference on Lasers and Electro-Optics (CLEO '97) (Baltimore, Maryland, May 1997), *CLEO '97 Technical Digest Series* (1997).

A. Babushkin, W. Seka, S. A. Letzring, W. Bittle, M. Labuzeta, M. Miller, and R. G. Rhodes, "Multicolor Fiducial Laser for Streak Cameras and Optical Diagnostics for the OMEGA Laser System," 22nd International Congress on High-Speed Photography and Photonics (Santa Fe, New Mexico, October–November 1996), *SPIE Proceedings* **2869**, 540 (1997).

D. A. Baker and J. A. Phillips, “An Overview of Reversed-Field Pinch Research,” 2nd International Symposium on Evaluation of Current Trends in Fusion Research (Washington, D.C., March 1997), *Proceedings of the 2nd International Symposium on Evaluation of Current Trends in Fusion Research* (Plenum Press, 1997).

C. W. Barnes, J. B. Beck, P. L. Gobby, W. W. Hsing, N. M. Hoffman, H. N. Kornblum, T. J. Orzechoowski, D. Galmiche, and A. Richard, “Analysis of the Rayleigh-Taylor Instability in Cylindrical Convergent Geometry using Indirect Drive,” 27th Annual Anomalous Absorption Conference (Vancouver, Canada, May–June 1997).

C. W. Barnes, J. B. Beck, N. M. Hoffman, W. W. Hsing, D. Galmiche, and A. Richard, “Nonlinear Mode Coupling in Cylindrical Implosions,” 39th Annual Meeting of the Division of Plasma Physics of the American Physical Society (Pittsburgh, Pennsylvania, November 1997).

C. W. Barnes and H. A. Davis, “High Power Pulsed Diagnostic Neutral Beam,” Design of ITER Diagnostic Systems (San Diego, California, February 1997).

C. W. Barnes, D. L. Jassby, G. L. LeMunyan, A. L. Roquemore, and C. Walker, “Design Considerations for Neutron Activation and Neutron Source Strength Monitors for ITER,” Diagnostics for Experimental Fusion Reactions (Varenna, Italy, September 1997).

D. C. Barnes, R. A. Nebel, M. M. Schauer, and M. M. Pickrel, “Inertial Electro-Magnetostatic Plasma Neutron Sources,” IEEE International Conference on Plasma Science (San Diego, California, May 1997).

D. C. Barnes, M. M. Schauer, T. B. Mitchell, R. A. Nebel, and F. L. Ribe, “Dense Nonneutral Plasmas and Fusion Applications,” Nonneutral Plasmas (Boulder, Colorado, July 1997).

J. B. Beck, W. W. Hsing, C. W. Barnes, and N. M. Hoffman, “Rayleigh-Taylor Growth of Unstable Perturbations in Ablatively Driven Cylindrical Implosions,” Laser Interactions and Related Plasma Phenomena (Monterey, California, April 1997).

J. F. Benage, Jr., G. A. Kyrala, J. Workman, and T. Tierney, “Measuring the EOS of a Dense, Strongly Coupled Plasma; Description of the Technique,” Strongly Coupled Coulomb Systems (Boston, Massachusetts, August 1997).

J. F. Benage, Jr., G. A. Kyrala, J. Workman, and T. Tierney, “Measuring the EOS of a Dense, Strongly Coupled Plasma: Description of the Technique and Preliminary Results,” Boston College Seminar (Boston, Massachusetts, August 1997).

J. F. Benage, Jr., F. J. Wysocki, R. Bowers, H. Oona, W. Broste, R. Harper, and N. Roderick, "Experiments on Planar Plasma Flow Switches at Los Alamos," 11th IEEE International Pulsed Power Conference (Baltimore, Maryland, June–July 1997), *Proceedings of the 11th IEEE International Pulsed Power Conference* 2, 1233 (1997).

R. R. Berggren and R. A. Schmell, "Pad Polishing for Rapid Production of Large Flats," Optical Manufacturing and Testing II (San Diego, California, July 1997), *SPIE Proceedings* 3134, 252 (1997).

B. Bezzerides, D. S. Montgomery, H. X. Vu, J. M. Wallace, and B. H. Wilde, "Postprocessor for Brillouin and Raman Convective Gain," 27th Annual Anomalous Absorption Conference (Vancouver, Canada, May–June 1997).

R. L. Bolvin, M. Koltonyuk, C. P. Munson, and R. M. Mayo, "Time-of-Flight Neutral Particle Analyzer for Alcator C-Mod," 11th Topical Conference on High-Temperature Plasma Diagnostics (Monterey, California, May 1996), *Review of Scientific Instruments* 68, 982 (1997).

D. W. Bowman, G. A. Bennett, F. A. Biehl, J. C. Cochrane, R. F. Gribble, J. R. Griego, R. D. Hicks, W. B. Hinckley, K. W. Hosack, R. J. Kasik, E. A. Lopez, W. A. Reass, H. R. Salazar, G. M. Sandoval, D. W. Scudder, M. C. Thompson, W. M. Parsons, "Design of the Atlas 240 kV Marx Modules," 11th IEEE International Pulsed Power Conference (Baltimore, Maryland, June–July 1997), *Proceedings of the 11th IEEE International Pulsed Power Conference* 1, 498 (1997).

G. E. Busch, C. J. Hewitt, W. T. Leland, D. K. Remelius, T. Shimada, C. E. M. Strauss, D. C. Thompson, and C. W. Wilson, "Acousto-Optically Tuned Isotopic CO_2 Lasers for Long-Range Differential Absorption Lidar," Conference on Lasers and Electro-Optics (CLEO '97) (Baltimore, Maryland, May 1997), *CLEO '97 Technical Digest Series* 11, 188 (1997).

G. E. Busch, W. T. Leland, D. K. Remelius, T. Shimada, C. E. M. Strauss, D. C. Thompson, C. W. Wilson, and T. J. Zaugg, "High-Repetition-Rate Rapid-Tuning CO_2 Laser Development," CALIOPE (Livermore, California, February 1997).

S. E. Caldwell, S. R. Goldman, W. W. Hsing, D. J. Thoma, M. D. Wilke, and D. C. Wilson, "Shock Front Evolution in Non-Uniform Materials," 39th Annual Meeting of the Division of Plasma Physics of the American Physical Society (Pittsburgh, Pennsylvania, November 1997).

S. E. Caldwell, S. R. Goldman, M. D. Wilke, and D. C. Wilson, "Effect of Joints and Gaps on Shock Propagation," 27th Annual Anomalous Absorption Conference (Vancouver, Canada, May–June 1997).

A. Castro and J. Williams, "Ultrasensitive, Direct Detection of Specific Target Genes," Single Molecule Detection (Berlin, Germany, September 1997).

H.-W. Chen, C. J. Aine, E. Flynn, and C. C. Wood, "Spatial Frequency Tuning Functions and Contrast Sensitivity at Different Eccentricities of Visual Field," Biomag96: Advances in Biomagnetic Research (Santa Fe, New Mexico, February 1996), *Biomag96: Advances in Biomagnetic Research* (Springer-Verlag, New York, 1997).

H.-W. Chen, C. J. Aine, E. Flynn, and C. C. Wood, "Spatio-Temporal Interactions in Human Vision using Transient and M-Sequence Stimuli," Biomag96: Advances in Biomagnetic Research (Santa Fe, New Mexico, February 1996), *Biomag96: Advances in Biomagnetic Research (*Springer-Verlag, New York, 1997).

V. K. Chernyshev, V. N. Mokhov, V. N. Buzin, O. M. Burenkov, A. M. Bujko, V. V. Vakhrushev, S. F. Garanin, B. E. Grinevich, Y. N. Gorbachev, V. A. Demidov, V. I. Dudoladov, V. V. Zmushko, A. I. Kuzyaev, A. I. Kucherov, B. M. Lovyagin, Y. I. Matsev, P. N. Nizovtsev, A. A. Petrukhin, A. I. Pishchurov, S. S. Sokolov, V. P. Solovjov, A. I. Startsev, V. B. Yakubov, B. A. Anderson, C. A. Ekdahl, D. Goforth, D. A. Clark, I. R. Lindemuth, R. E. Reinovsky, R. Fail, and S. M. Younger, "Study of High-Energy Liner Compression in HEL-1 Experiment," 11th IEEE International Pulsed Power Conference (Baltimore, Maryland, June–July 1997), in *Proceedings of the 11th IEEE International Pulsed Power Conference* 1, 566 (1997).

R. E. Chrien, F. J. Swenson, B. H. Wilde, D. L. Peterson, W. Matuska, W. E. Anderson, G. Idzorek, J. L. Porter, R. Spielman, C. Deeney, G. A. Chandler, and D. L. Fehl, "Vacuum Hohlraum Experiments on PBFA-Z," 39th Annual Meeting of the Division of Plasma Physics of the American Physical Society (Pittsburgh, Pennsylvania, November 1997), *Bulletin of the American Physical Society* 42, 1879 (1997).

D. A. Clark, B. G. Anderson, C. A. Ekdahl, R. J. Faehl, J. H. Goforth, I. R. Lindemuth, T. L. Peterson, R. E. Reinovsky, L. J. Tabaka, V. K. Chernyshev, V. N. Moknov, V. N. Buzin, O. M. Byrenkov, A. M. Bujko, V. V. Vakhruchev, S. F. Garanin, B. E. Grinevich, Y. N. Gorbachov, E. B. Gubkov, B. A. Demidov, V. I. Dudoladov, V. V. Zmushko, A. I. Kuzyaev, A. I. Kucherov, B. M. Lovyagin, Y. I. Matsev, P. N. Nizovtsev, A. A. Petrukhin, A. I. Pishurov, S. S. Sokolov, V. P. Solovjov, A. I. Startsev, and V. B. Yakubov, "High Energy Imploding Liner Experiment HEL-1: Experimental Results," 11th IEEE International Pulsed Power Conference (Baltimore, Maryland, June–July 1997), in *Proceedings of the 11th IEEE International Pulsed Power Conference* 2, 1369 (1997).

B. P. Cluggish and B. P. Wood, "Deposition of Metal Coatings on the Inside Surface of Pipes using a Cathodic Arc Plasma," 39th Annual

Meeting of the Division of Plasma Physics of the American Physical Society (Pittsburgh, Pennsylvania, November 1997).

B. P. Cluggish and B. P. Wood, “Transport of a Cathodic Arc Plasma Inside a Magnetized Tube,” IEEE International Conference on Plasma Science (San Diego, California, May 1997).

J. A. Cobble, A. V. Bessarab, A. V. Kunin, V. A. Tokarev, and S. R. Goldman, “Radiation Temperature Measurements in Laser-Heated Hohlraums,” 9th Topical Conference on High Temperature Plasma Diagnostics (St. Petersburg, Russia, June 1997), *Fizika Plazmy* 24, 208 (1998).

J. A. Cobble, R. P. Johnson, and R. J. Mason, “F Number Increase of a High-Intensity Green Laser Beam in a Plasma,” 39th Annual Meeting of the Division of Plasma Physics of the American Physical Society (Pittsburgh, Pennsylvania, November 1997).

M. D. Cooper, “New Ideas to Improve Searches for $\mu^+ \rightarrow e^+\gamma$,” Workshop on Physics at the First Muon Collider and at the Front End of a Muon Collider (Batavia, Illinois, November 1997), in *Proceedings of the Workshop on Physics at the First Muon Collider and at the Front End of a Muon Collider*, S. Geer and R. Raga, Eds. (AIP, New York, 1998).

M. D. Cooper, M. L. Brooks, G. E. Hogan, V. D. Laptev, R. E. Mischke, P. S. Cooper, Y. Chen, M. Dzemidzic, A. Empl, E. V. Hungerford, K. Lan, W. von Witsch, K. Stantz, J. J. Szymanski, C. A. Gagliardi, R. E. Tribble, D. D. Koetke, R. Manweiler, S. Stanislaus, K. O. H. Ziock, and L. E. Pillonen, “Lepton Flavor Violation,” 6th Conference on the Intersections of Particle and Nuclear Physics (Big Sky, Montana, May 1997), in *Proceedings of the 6th Conference on the Intersections of Particle and Nuclear Physics*, T. W. Donnelly, Ed. (AIP, New York, 1998), p. 34.

B. E. Crawford, N. R. Roberson, S. J. Seestrom, C. M. Frankle, J. D. Bowman, S. I. Penttilä, A. Masaike, Y. Matsuda, T. Haseyama, E. I. Sharapov, and S. L. Stephenson, “Development of Apparatus for Capture g-Ray Studies of Parity Violation at Los Alamos,” 4th International Seminar on Neutron-Nucleus Interactions (Dubna, Russia, 1997), in *Proceedings of the Forth International Seminar on Neutron-Nucleus Interactions* (JINR, Dubna, 1997), p. 268.

H. A. Davis, B. P. Wood, C. P. Munson, L. J. Bitteker, M. A. Nastasi, D. J. Rej, W. J. Waganaar, K. C. Walter, D. M. Coates, and H. M. Schleinitz, “Ion Beam and Plasma Technology Development for Surface Modification at Los Alamos National Laboratory,” 4th IUMRS International Conference in Asia (Chiba, Japan, September 1997), *Materials Chemistry and Physics* 54, 213 (1998).

S. Davis, D. Barnes, T. Casper, R. Fonck, T. Fredian, T. Gibney, M. Greenwald, D. Greenwood, P. Henline, K. Keith, B. McHarg, W. Meyer, J. Moller, P. Roney, J. Stillerman, and G. A. Wurden, “Experiences with Remote Collaborations in Fusion Research,” 17th IEEE/ NPSS Symposium on Fusion Engineering (San Diego, California, October 1997).

N. D. Delamater, E. L. Lindman, Jr., G. R. Magelssen, B. A. Failor, A. L. Richard, R. E. Chrien, R. Peterson, S. M. Pollaine, L. J. Suter, O. Landen, S. N. Dixit, J. B. Moore, V. Gomez, K. Gifford, and B. Hammel, “Symmetry Experiments in Gas Filled Hohlraums with Smooth Beams at Nova,” 27th Annual Anomalous Absorption Conference (Vancouver, Canada, May–June 1997).

B. G. de Volder, T. J. T. Kwan, R. D. Fulton, D. C. Moir, D. M. Oró, and D. S. Prono, “Computational and Experimental Studies of the Beam-Target Interaction for High-Dose, Multi-Pulse Radiography,” IEEE International Conference on Plasma Science (San Diego, California, May 1997).

M. A. Espy, “Other Options: SQUIDs,” Workshop on a New Experiment for Measuring the Neutron’s Electric Dipole Moment (Los Alamos, New Mexico, March 1997).

R. J. Faehl, W. L. Atchison, R. E. Reinovsky, and D. V. Morgan, “Numerical and Experimental Studies of Magnetic Rayleigh-Taylor Instabilities in Solid Liners,” IEEE International Conference on Plasma Science (San Diego, California, May 1997).

A. Ya Faenov, J. Abdallah, R. E. H. Clark, Jr. , J. Cohen, R. P. Johnson, G. A. Kyrala, A. I. Magunov, T. A. Pikuz, I. Yu. Skobelev, and M. D. Wilke, “High-Resolution X-Ray Spectroscopy of Hollow Atoms Created in Plasma Heated by Subpicosecond Laser Radiation,” Applications of X-Rays Generated from Lasers and Other Bright Sources (San Diego, California, July–August 1997), *SPIE Proceedings* 3157, 10 (1997).

J. C. Fernández, B. S. Bauer, J. A. Cobble, D. F. DuBois, G. A. Kyrala, D. S. Montgomery, H. A. Rose, H. X. Vu, R. G. Watt, B. H. Wilde, M. D. Wilke, W. M. Wood, B. H. Failor, R. Kirkwood, and B. J. MacGowan, “Measurements of Laser-Plasma Instability Relevant to Ignition Hohlraums,” 38th Annual Meeting of the Division of Plasma Physics of the American Physical Society (Denver, Colorado, November 1996), *Physics of Plasmas* 4, 1849 (1997).

J. C. Fernández, J. A. Cobble, D. S. Montgomery, H. A. Rose, and M. D. Wilke, “Stimulated Raman Scattering in a Long-Scale Hohlraum Plasma,” 39th Annual Meeting of the Division of Plasma Physics of the American Physical Society (Pittsburgh, Pennsylvania, November 1997).

D. H. Fitzgerald, H. E. Ahn, B. Blind, M. J. Borden, R. J. Macek, F. Neri, C. R. Rose, H. A. Thiessen, C. A. Wilkinson, and M. V. Zumbro, "Overview and Status of the Los Alamos PSR Injection Upgrade Project," Particle Accelerator Conference (Vancouver, Canada, May 1997).

E. Flynn, R. Bracht, R. H. Kraus, Jr., P. M. Maas, P. Ruminer, and M. Stettler, "A Digital-Signal-Processor (DSP) Flux-Locked Loop (FLL) for SQUIDs with Automatic Reset and Feedback Cancellation," Biomag96: Advances in Biomagnetic Research (Santa Fe, New Mexico, February 1996), *Biomag96: Advances in Biomagnetic Research* (Springer-Verlag, New York, 1997).

J. R. Frigo, K. R. Moore, and M. W. Tilden, "A Novel Microsatellite Control System," International Workshop on Applications of Neural Networks to Telecommunications (Melbourne, Australia, June 1997).

J. R. Frigo and M. W. Tilden, "Analog Neural Network Control Method Proposed for Use in a Backup Satellite Control Mode," Mobile Robots XII (Pittsburgh, Pennsylvania, October 1997), *SPIE Proceedings* 3210, 84 (1998).

D. J. Funk, B. W. Asay, J. L. Mace, R. L. Rabie, B. I. Bennett, Jr., J. D. Bowman, V. W. Yuan, G. L. Morgan, R. M. Boat, L. M. Hull, B. F. Henson, R. S. Hixson, G. W. Laabs, D. M. Murk, H. L. Stacy, and C. E. Ragan, "Dynamic Measurement of Temperature using Neutron Resonance Spectroscopy (NRS)," Shock Compression of Condensed Matter (Amherst, July 1997).

Gavron, K. Morley, C. Morris, S. Seestrom, J. Ullmann, G. Yates, and J. Zumbro, "High Energy Neutron Radiography," International Conference on Neutrons in Research and Industry (Crete, Greece, June 1997), *SPIE Proceedings* 2867, 326 (1997).

J. S. George and M. X. Huang, "Cingulate Sources during Photosensitive Epileptic Discharges Observed with Magnetoencephalography," 3rd International Conference on Functional Mapping of the Human Brain (Copenhagen, Denmark, May 1997).

J. S. George, D. M. Schmidt, J. C. Mosher, C. J. Aine, D. M. Ranken, C. C. Wood, J. D. Lewine, J. A. Sanders, and J. W. Belliveau, "Dynamic Neuroimaging by MEG, Constrained by MRI and fMRI," Biomag96: Advances in Biomagnetic Research (Santa Fe, New Mexico, February 1996), in *Biomag96: Advances in Biomagnetic Research* (Springer-Verlag, New York, 1997).

P. L. Gobby, D. J. Hatch, R. Manzanares, P. M. Brooks, H. Bush, Jr., J. E. Moore, V. M. Gomez, L. R. Foreman, J. M. Wallace, and T. J. Murphy, "Fabrication of Tetrahedral Hohlraums," 27th Annual Anomalous Absorption Conference (Vancouver, Canada, May–June 1997).

S. R. Goldman, C. W. Barnes, S. E. Caldwell, N. D. Delamater, W. W. Hsing, M. D. Wilke, D. C. Wilson, D. C. Wilson, M. Dunne, J. Edwards, P. Graham, and B. Thomas, “Target Joints in Cylindrical Geometry,” 39th Annual Meeting of the Division of Plasma Physics of the American Physical Society (Pittsburgh, Pennsylvania, November 1997).

S. R. Goldman, S. E. Caldwell, P. L. Gobby, W. W. Hsing, D. J. Thoma, R. P. Weaver, B. H. Wilde, M. D. Wilke, and D. C. Wilson, “Using Laser Drive to Probe the Physics of Structuring due to Target Defects,” 11th Biennial Nuclear Explosives Design Physics Conference (Livermore, California, October 1997).

S. R. Goldman, S. E. Caldwell, W. W. Hsing, M. D. Wilke, and D. C. Wilson, “Target Joints in Cylindrical Geometry,” 39th Annual Meeting of the Division of Plasma Physics of the American Physical Society (Pittsburgh, Pennsylvania, November 1997).

S. R. Goldman, M. D. Wilke, D. C. Wilson, and S. E. Caldwell, “Effect of Fabrication Defects on Targets with Beryllium Based Ablators,” 27th Annual Anomalous Absorption Conference (Vancouver, Canada, May–June 1997).

R. Guckert, V. D. Sandberg, D. Tupa, D. J. Vieira, and X. Zhao, “Progress towards Trapping ^{82}Rb in an Optical Trap,” 213th American Chemical Society National Meeting (San Francisco, California, April 1996), *Abstracts of Papers from the 213th American Chemical Society National Meeting* 213, NUCL-69 (1997).

M. S. Gulley, M. H. Holzscheiter, P. Kwiat, V. Sandberg, M. M. Schauer, D. Tupa, and R. J. Hughes, “Experimental Work on Quantum Computation at Los Alamos National Laboratory,” American Physical Society/AAPT Meeting (Washington, D.C., April 1997).

M. Gulley, X. M. Zhao, C. E. M. Strauss, D. J. Funk, G. A. Kyrala, W. B. Ingalls, H. C. Bryant, D. C. Rislove, W. A. Miller, and A. Stintz, “Nonresonant Two-Photon Detachment of H^- Ions with 1.17 eV Photons,” American Physical Society/AAPT Meeting (Washington, D.C., April 1997).

J. E. Hammerberg, B. I. Bennett, Jr., C. E. Ragan, B. L. Holian, R. R. Critchfield, R. S. Hixson, J. E. Vorthman, and V. W. Yuan, “Dynamic Experiment for Interface Physics,” 11th Biennial Nuclear Explosives Design Physics Conference (Livermore, California, October 1997).

B. Hasslacher and M. W. Tilden, “Theoretical Foundations for Nervous Networks and the Design of Living Machines,” Workshop on Control Mechanisms for Complex Systems: Issues of Measurement and Semiotic Analysis.

A. A. Hauer, G. A. Kyrala, J. S. Wark, T. Boehly, B. Remington, and D. H. Kalantar, "Use of X-Ray Backlighting in the Study of Transient X-Ray Diffraction in Moderate Pressure Shocks," SPIE Optical Science, Engineering, and Instrumentation (San Diego, California, July 1997).

A. A. Hauer, J. S. Wark, D. Kalantar, B. Remington, R. Kopp, J. Cobble, B. Failor, G. Kyrala, M. Meyers, R. Springer, and T. Boehley, "Transient X-Ray Diffraction and Its Application to Materials Science and X-Ray Optics," Applications of X-Rays Generated from Lasers and Other Bright Sources (San Diego, California, July–August 1997), *SPIE Proceedings* **3157**, 72 (1997).

L. Heller, M. Akhtari, and E. D. Best, "Dependence of EEG and MEG on Electric Conductivities," 3rd International Conference on Functional Mapping of the Human Brain (Copenhagen, Denmark, May 1997).

R. E. Hill, T. J. Bowles, S. J. Seestrom, T. O. Brun, and C. L. Morris, "Progress on Development of an Ultracold Neutron Source at the Los Alamos Neutron Science Center," Meeting of the Division of Nuclear Physics of the American Physical Society (Whistler, Canada, October 1997).

A. Hime, "Neutral-Current Detectors for the Sudbury Neutrino Observatory," Solar Neutrino Conference (Heidelberg, Germany, April 1997).

D. E. Hollowell, G. T. Schappert, R. P. Weaver, S. E. Caldwell, and W. W. Hsing, "Ablative Rayleigh-Taylor Instability Modeling," 11th Biennial Nuclear Explosives Design Physics Conference (Livermore, California, October 1997).

D. E. Hollowell, G. T. Schappert, R. P. Weaver, S. E. Caldwell, and W. W. Hsing, "Ablative Rayleigh-Taylor Instability Modeling," 27th Annual Anomalous Absorption Conference (Vancouver, Canada, May–June 1997).

M. H. Holzscheiter, G. Bendiscioli, A. Bertin, G. Bollen, M. Bruschi, C. Cesar, M. Charlton, M. Corradini, D. DePedis, M. Doser, J. Eades, R. Fedele, X. Feng, F. Galluccio, T. Goldman, J. S. Hangst, R. Hayano, D. Horvath, R. J. Hughes, N. S. P. King, K. Kirsebom, H. Knudsen, V. Lagomarsino, R. Landua, G. Laricchia, R. A. Lewis, E. Lodi Rizzini, M. Macri, G. Manuzio, U. Marconi, M. R. Masullo, J. P. Merrison, S. P. Møller, G. L. Morgan, M. M. Nieto, M. Piccinini, R. Poggiani, A. Rotondi, G. Rouleau, P. Salvini, N. Semprini-Cesari, G. A. Smith, C. M. Surko, G. Testera, G. Torelli, E. Uggerhøj, V. G. Vaccaro, L. Venturelli, A. Vitale, E. Widmann, T. Yamazaki, Y. Yamazaki, D. Zanello, and A. Zoccoli, "Antihydrogen Production and Precision Experiments," Antimatter Gravity and Antihydrogen Spectroscopy International Workshop (Sepino, Italy, May 1996), *Hyperfine Interactions* **109**, 1 (1997).

M. H. Holzscheiter, G. Bendiscioli, A. Bertin, G. Bollen, M. Bruschi, C. Cesar, M. Charlton, M. Corradini, D. DePedis, M. Doser, J. Eades, R. Fedele, X. Feng, F. Galluccio, T. Goldman, J. S. Hangst, R. Hayano, D. Horvath, R. J. Hughes, N. S. P. King, K. Kirsebom, H. Knudsen, V. Lagomarsino, R. Landua, G. Laricchia, R. A. Lewis, E. Lodi Rizzini, M. Macri, G. Manuzio, U. Marconi, M. R. Masullo, J. P. Merrison, S. P. Møller, G. L. Morgan, M. M. Nieto, M. Piccinini, R. Poggiani, A. Rotondi, G. Rouleau, P. Salvini, N. Semprini-Cesari, G. A. Smith, C. M. Surko, G. Testera, G. Torelli, E. Uggerhøj, V. G. Vaccaro, L. Venturelli, A. Vitale, E. Widmann, T. Yamazaki, Y. Yamazaki, D. Zanello, and A. Zoccoli, "Antihydrogen Production and Precision Experiments," 4th Biennial Conference on Low Energy Antiproton Physics (Dinkelsbuhl, Germany, August 1996), *Nuclear Physics B* 56, 336 (1997).

W. W. Hsing, C. W. Barnes, J. B. Beck, N. M. Hoffman, D. Galmiche, A. Richard, J. Edwards, P. Graham, S. Rothman, and B. Thomas, "Rayleigh-Taylor Instability Evolution in Ablatively Driven Cylindrical Implosions," 38th Annual Meeting of the Division of Plasma Physics of the American Physical Society (Denver, Colorado, November 1996), *Physics of Plasmas* 4, 1832 (1997).

W. W. Hsing, S. E. Caldwell, S. R. Goldman, and R. P. Weaver, "Shock Propagation in the Nonlinear Regime," 39th Annual Meeting of the Division of Plasma Physics of the American Physical Society (Pittsburgh, Pennsylvania, November 1997).

M. Huang and L. Heller, "One Effect of a Maximum Possible Current Strength," Biomag96: Advances in Biomagnetic Research (Santa Fe, New Mexico, February 1996), *Biomag96: Advances in Biomagnetic Research* (Springer-Verlag, New York, 1997).

M. Huang and J. C. Mosher, "A Novel Head Model for the MEG Forward Problem: BEM Accuracy with Only Spherical Model Complexity," 3rd International Conference on Functional Mapping of the Human Brain (Copenhagen, Denmark, 1997), abstract in *Neuroimage* 5, 441 (1997).

M. Huang, J. C. Mosher, R. M. Leahy, M. E. Spencer, and C. C. Wood, "Comparing the Accuracy of EEG and MEG Source Localization using a Human Skull Phantom," 27th Annual Meeting of the Society for Neuroscience (New Orleans, Louisiana, October 1997).

M. Huang, S. Supek, and C. Aine, "Multi-Source Localization in MEG using Simulated Annealing: Model Order Determination and Parameter Accuracy," Biomag96: Advances in Biomagnetic Research (Santa Fe, New Mexico, February 1996), *Biomag96: Advances in Biomagnetic Research* (Springer-Verlag, New York, 1997).

R. J. Hughes, "Secure Communications Using Quantum Cryptography," Photonic Quantum Computing (Orlando, Florida, April 1997), *SPIE*

Proceedings **3076**, 2 (1997); *SPIE Newsletters* **8** (1997); and *OE Reports* **164**, 12 (1997).

R. J. Hughes and D. F. James, "Prospects for Quantum Computation with Trapped Ions," Fundamental Problems in Quantum Theory (Baltimore, Maryland, August 1997).

R. J. Hughes, G. G. Luther, G. L. Morgan, C. G. Peterson, and C. M. Simmons, "Quantum Cryptography Over 24 km of Underground Optical Fibers," American Physical Society/AAPT Meeting (Washington, D.C., April 1997).

D. Hywel White, A. Ajduk, and A. K. Wroblewski, "LSND Neutrino Oscillation Results," 28th International Conference on High-Energy Physics (Warsaw, Poland, July 1996).

G. C. Idzorek and R. J. Bartlett, "Silicon Photodiode Characterization from 1 eV to 10 keV," SPIE Optical Science, Engineering, and Instrumentation (San Diego, California, July 1997).

G. C. Idzorek and R. J. Bartlett, "Silicon Photodiode Soft X-Ray Detectors," IEEE International Conference on Plasma Science (San Diego, California, May 1997).

G. C. Idzorek and R. J. Bartlett, "Silicon Photodiode Soft X-Ray Detectors for Pulsed Power Experiments," 11th IEEE International Pulsed Power Conference (Baltimore, Maryland, June–July 1997), *Proceedings of the 11th IEEE International Pulsed Power Conference* **2**, 1274 (1997).

G. C. Idzorek and H. Oona, "Soft X-Ray Diagnostics for MAGO Experiments," Innovative Confinement Concepts Workshop (Marina del Rey, California, March 1997).

D. F. V. James, R. J. Hughes, E. H. Knill, R. Laflamme, and A. G. Petschek, "Decoherence Bounds on the Capabilities of Cold Trapped Ion Quantum Computers," Photonic Quantum Computing (Orlando, Florida, April 1997), *SPIE Proceedings* **3076**, 42 (1997).

L. C. Johnson, C. W. Barnes, K. Ebisawa, A. V. Krasilnikov, F. B. Markus, T. Nishitani, G. J. Sadler, and C. Walker, "Overview of Fusion Product Diagnostics for ITER," Diagnostics for Thermonuclear Reactors (Varenna, Italy, September 1997).

J. S. Kapustinsky, J. G. Boissevain, E. J. Bosze, D. J. Clark, D. M. Jaffe, S. Y. Kim, L. J. Marek, J. Simon-Gillo, J. P. Sullivan, H. W. van Hecke, and G. Xu, "Double-Metal Silicon Pad Design for the Phenix Multiplicity/ Vertex Detector," Frontier Detectors for Frontier Physics (Isola D'Elba, Italy, May 1997).

R. R. Karl, Jr., W. K. Grace, J. R. Busse, N. A. Kurnit, A. C. Koskelo, and O. G. Peterson, “Data Analysis of Lidar Measurements of Atmospheric Boundary Layer Aerosols from a Black Hawk Helicopter,” Geosciences and Remote Sensing Symposium (Singapore, August 1997).

R. R. Karl, Jr., N. A. Kurnit, and W. Hungate, “Atmospheric Aerosol Monitoring by 1.54 μm Eyesafe Elastic Backscatter Lidar from a Black Hawk Helicopter,” Airborne Remore Sensing Conference (Copenhagen, Denmark, July 1997).

R. K. Keinigs, R. J. Faehl, and D. Platts, “Modeling of a Soft X-Ray Diode using Particle-in-Cell and Monte-Carlo Simulations,” IEEE International Conference on Plasma Science (San Diego, California, May 1997).

R. K. Keinigs, H. Lee, and R. J. Trainor, “Current/Performance Scaling Studies for the Altas Project,” 11th Biennial Nuclear Explosives Design Physics Conference (Livermore, California, October 1997).

N. S. P. King, T. E. McDonald, and G. J. Yates, “Ultra-Fast CCD Framing Camera using Imageline Record and Shift Concept,” 43rd International Instrumentation Symposium (Orlando, Florida, May 1997).

R. C. Kirkpatrick and G. C. Idzorek, “Analysis of Filtered Silicon Diode Data from MAGO/MTF Experiments,” IEEE International Conference on Plasma Science (San Diego, California, May 1997).

R. C. Kirkpatrick and G. C. Idzorek, “Analysis of Filtered Silicon Diode Data from the MAGO-II and MAGO-III Experiments,” Innovative Confinement Concepts Workshop (Marina del Rey, California, March 1997).

K. A. Klare, J. M. Wallace, and D. Drake, “Tetrahedral Hohlraum Visualization and Pointings,” 39th Annual Meeting of the Division of Plasma Physics of the American Physical Society (Pittsburgh, Pennsylvania, November 1997).

J. N. Knudson, S. J. Seestrom, J. D. Bowman, B. E. Crawford, P. P. J. Delheij, T. Haseyama, L. Lowie, A. Masaike, Y. Matsuda, G. E. Mitchell, N. R. Roberson, S. I. Penttilä, Y. Popov, H. Postma, E. I. Sharapov, S. L. Stephenson, Y.-F. Yen, V. W. Yuan, and S. H. Yoo, “Study of Parity Nonconservation with Epithermal Neutrons,” International Conference on Neutrons in Research and Industry (Crete, Greece, June 1997), in *SPIE Proceedings* 2867, 388 (1997).

R. A. Kopp, A. A. Hauer, and W. W. Hsing, “Laser Pulse Shaping for Direct-Drive EOS Experiments on Trident Upgrade,” 27th Annual Anomalous Absorption Conference (Vancouver, Canada, May–June 1997).

T. Kozlowski, E. Desmond, J. Haggerty, H.-J. Kehayias, M. Purschke, and C. Witzig, “Analysis, Design, and Implementation of PHENIX On-Line Computing Systems Software using Shlaer-Mellor Object-Oriented Analysis and Recursive Design,” International Conference on Computing in High Energy Physics (Berlin, Germany, April 1997), *Computer Physics Communications* 110, 164 (1998).

R. H. Kraus, Jr., R. Bracht, E. R. Flynn, Q. Jia, P. M. Maas, D. Reagor, and M. Stettler, “A Digital Flux-Locked Loop for High Temperature SQUID Magnetometer and Gradiometer Systems with Field Cancellation,” Biomag96: Advances in Biomagnetic Research (Santa Fe, New Mexico, February 1996), *Biomag96: Advances in Biomagnetic Research* (Springer-Verlag, New York, 1997).

N. A. Kurnit, R. F. Harrison, R. R. Karl, Jr., J. P. Brucker, J. R. Busse, W. K. Grace, O. G. Peterson, and W. Hungate, “Generation of 1.54 µm Radiation with Application to an Eyesafe Laser Lidar,” Lasers ’97 (New Orleans, Louisiana, December 1997).

K. Kwiatkowski, “Heating Nuclei with Antiprotons,” Workshop on Fixed Target Physics with the 120-GeV FNAL Main Injector, Antiproton Working Group at Fermi National Accelerator Laboratory (Batavia, Illinois, May 1997).

K. Kwiatkowski, “Multifragmentation: Thermal vs. Dynamic Effects,” 6th International Conference on Nucleus-Nucleus Collisions (Gatlinburg, Tennessee, June 1997), *Nuclear Physics A* 630, 168c (1998).

K. Kwiatkowski, D. Bracken, E. Foxford, K. B. Morley, V. E. Viola, G. Wang, R. G. Korteling, R. Legrain, E. C. Pollacco, and C. Volant, “Ion-induced Multifragmentation,” 35th International Winter Meeting on Nuclear Physics (Bormio, Italy, February 1997), *Proceedings of 35th International Winter Meeting on Nuclear Physics*, p. 432.

K. Kwiatkowski, W.-C. Hsi, G. Wang, A. Botvina, D. S. Bracken, H. Breuer, E. Cornell, W. A. Friedman, F. Gimeno-Nogues, D. S. Ginger, S. Gushue, M. J.Huang, R. G. Korteling, W. G. Lynch, K. B. Morely, E. C. Pollacco, E. Ramakrishnan, L. P. Remsberg, D. Rowland, M. B. Tsang, V. E. Viola, C. Volant, H. Xi, and S. J. Yennello, “Dynamic and Statistical Effects in Light-Ion-Induced Multifragmentation,” in *Advances in Nuclear Dynamics 4,* W. Bauer and H. G. Ritter, Eds. (Plenum Press, 1998), p. 173.

G. A. Kyrala, “Intense Sub-nm X-Ray Generation for Diagnostic Applications,” International Workshop on Measurements of the Ultrafast Dynamics (Esterel, June 1997).

G. A. Kyrala, A. Ya Faenov, T. Pikuz, M. Wilke, J. Abdallah, Jr., and R. P. Johnson, “Intense Sub-nm X-Ray Generation for Diagnostic Applications,” Measurements of the Ultrafast Dynamics of Complex Systems (Montreal, Canada, June 1997).

G. A. Kyrala, R. P. Johnson, and N. K. Moncur, “Effect of Laser Prepulse on the Efficiency of Generations of X-Rays,” 39th Annual Meeting of the Division of Plasma Physics of the American Physical Society (Pittsburgh, Pennsylvania, November 1997).

G. A. Kyrala, M. D. Wilke, R. P. Johnson, J. Abdallah, Jr., A. Ya Faenov, and T. Pikuz, “KeV X-Ray Generation with Powerful Sub-Picosecond Lasers,” Physics of Quantum Electronics (Snowbird, Utah, January 1997).

R. M. Leahy, J. C. Mosher, and J. W. Phillips, “A Comparative Study of Minimum Norm Inverse Methods for MEG Imaging,” Biomag96: Advances in Biomagnetic Research (Santa Fe, New Mexico, February 1996), *Biomag96: Advances in Biomagnetic Research* (Springer-Verlag, New York, 1997).

H. Lee, R. R. Bartsch, R. L. Bowers, W. Anderson, W. L. Atchison, R. E. Chrien, J. Cochrane, H. Oona, D. Platts, M. Rich, W. R. Shanahan, D. W. Scudder, J. Stokes, L. Veeser, and W. Broste, “Megabar Liner Experiments on Pegasus II,” 11th IEEE International Pulsed Power Conference (Baltimore, Maryland, June–July 1997), *Proceedings of the 11th IEEE International Pulsed Power Conference* 1, 366 (1997).

M. J. Leitch, “New Results from Fermilab E866: $\bar{d}/\bar{u}$ of the Proton and Nuclear Effects in J/Psi Production,” Meeting of the Division of Nuclear Physics of the American Physical Society (Whistler, Canada, October 1997).

I. R. Lindemuth, C. Ekdahl, R. C. Kirkpatrick, R. E. Reinovsky, R. E. Siemon, P. T. Sheehey, and F. J. Wysocki, “MAGO/MTF: Controlled Thermonuclear Fusion with Existing Pulse Power Systems?” 11th IEEE International Pulsed Power Conference (Baltimore, Maryland, June–July 1997).

I. R. Lindemuth, C. Ekdahl, R. C. Kirkpatrick, R. E. Reinovsky, R. E. Siemon, P. T. Sheehey, and F. J. Wysocki, “Role of Z-Pinches and Other Related Configurations in MAGO/MTF, a Low-Cost Approach to Controlled Thermonuclear Fusion,” Dense Z-Pinches (Vancouver, Canada, May 1997).

E. L. Lindman, Jr., G. R. Magelssen, J. M. Wallace, N. M. Hoffman, D. C. Wilson, N. D. Delamater, and M. D. Wilke, “Modeling of Symmetry and Drive in Inertial-Confinement Targets at Los Alamos National Laboratory,” Current Trends in International Fusion Research (Washington, D.C., March 1997).

E. A. Lopez, G. A. Bennett, R. R. Bartsch, J. C. Cochrane, J. R. Griego, R. D. Hicks, W. B. Hinckley, K. W. Hosack, R. J. Kasik, A. Marquez, W. M. Parsons, W. A. Reass, M. C. Thompson, and D. Casper, "Rail Gap Switch Modifications and Test Data for the Altas Capacitor Bank," 11th IEEE International Pulsed Power Conference (Baltimore, Maryland, June–July 1997), *Proceedings of the 11th IEEE International Pulsed Power Conference* 2, 881 (1997).

W. C. Louis, "LSND Neutrino Oscillation Results," Beyond the Desert Workshop on Particle Physics (Castle Ringberg, Germany, June 1997).

W. C. Louis, "LSND Neutrino Oscillation Results and Implications," Neutrinos in Astro, Particle, and Nuclear Physics, International School of Nuclear Physics (Erice, Italy, September 1997), *Progress in Particle and Nuclear Physics* 40, 151 (1998).

B. Luetkenhoener, R. Greenblatt, M. Hamalainen, J. Mosher, M. Scherg, C. Tesche, and P. Valdes-Sosa, "Comparison Between Different Approaches to the Biomagnetic Inverse Problem—Workshop Report," Biomag96: Advances in Biomagnetic Research (Santa Fe, New Mexico, February 1996), *Biomag96: Advances in Biomagnetic Research* (Springer-Verlag, New York, 1997).

G. R. Magelssen, R. E. Chrien, D. C. Wilson, and B. H. Wilde, "Integrated Capsule Experiments on Nova," 11th Biennial Nuclear Explosives Design Physics Conference (Livermore, California, October 1997).

R. J. Maqueda, G. A. Wurden, J. Terry, and J. A. Stillerman, "IR Imaging of Divertor Heat Loads in Alcator Co-Md1," 11th IEEE International Pulsed Power Conference (Baltimore, Maryland, June–July 1997).

R. J. Maqueda, G. A. Wurden, J. Terry, and J. A. Stillerman, "IR Imaging of Divertor Heat Loads in Alcator Co-Md1," 39th Annual Meeting of the Division of Plasma Physics of the American Physical Society (Pittsburgh, Pennsylvania, November 1997).

B. L. Marrone, J. H. Jett, R. A. Keller, J. C. Martin, R. C. Habbersett, S. Burde, W. P. Ambrose, Z. Huang, Y. Kim, C. R. Kuske, A. Castro, and R. T. Okinaka, "Microbial DNA Fingerprinting by DNA Fragment Sizing Flow Cytometry," Chemical and Biological Defense Research (Aberdeen Proving Ground, Maryland, November 1997).

F. J. Marshall and J. A. Oertel, "Framed Monochromatic X-Ray Microscope for ICF (Invited)," 11th Topical Conference on High-Temperature Plasma Diagnostics (Monterey, California, May 1996), *Review of Scientific Instruments* 68, 735 (1997).

E. R. Martin, B. G. Anderson, L. L. Sprouse, and R. L. York, “New Neutron Controller for Monitoring Pedestrians and Vehicles for Plutonium at the Sensitive Access Control Points of a Nuclear Facility,” IEEE Nuclear Symposium (Albuquerque, New Mexico, November 1997).

R. J. Mason, R. A. Kopp, S. R. Goldman, D. C. Wilson, and R. G. Watt, “Structural Effects in ICF Foam-Buffered Targets,” 11th Biennial Nuclear Explosives Design Physics Conference (Livermore, California, October 1997).

R. J. Mason, R. A. Kopp, H. X. Vu, D. C. Wilson, S. R. Goldman, and R. G. Watt, “Foam Buffered Laser-Matter Interactions,” Laser Interactions and Related Plasma Phenomena (Monterey, California, April 1997).

R. J. Mason, R. A. Kopp, R. G. Watt, and D. C. Wilson, “Structural Effects in Foam-Buffered Laser-Matter Interactions,” 39th Annual Meeting of the Division of Plasma Physics of the American Physical Society (Pittsburgh, Pennsylvania, November 1997).

W. Matuska, R. J. Bartlett, G. Idzorek, E. L. Lindman, Jr., D. L. Peterson, C. E. Ragan, and M. Rich, “Interpreting Saturn Hohoraum Behavior,” 11th Biennial Nuclear Explosives Design Physics Conference (Livermore, California, October 1997).

D. Mayo, J. E. Koster, R. O. Nelson, S. A. Wender, H. M. Blann, V. Brown, P. Anthony, L. F. Hansen, B. Pohl, T. C. Sangster, D. Krofcheck, F. P. Brady, J. L. Romero, D. M. Skopik, E. Hallin, H. Hifenecker, and J. A. Pinston, “Neutron Proton Bremsstrahlung Inclusive Photon Measurement at LANSCE/WNR: Results for Tn from 100 to 280 MeV,” Meeting of the Division of Nuclear Physics of the American Physical Society (Whistler, Canada, October 1997).

J. B. McClelland, “Proton Radiography: A New Way to Dynamically Image Thick Systems,” IUCF Meeting (Bloomington, March 1997).

D. D. Meyerhoffer, T. R. Boehly, D. H. Kalantar, J. P. Knauer, D. K. Bradley, R. L. Keck, R. J. Taylor, V. A. Smalyuk, W. Seka, C. P. Verdon, R. G. Watt, and O. Willi, “Performance of Planar Foam-Buffered Targets on the Omega Laser System,” 27th Annual Anomalous Absorption Conference (Vancouver, Canada, May–June 1997).

G. E. Mitchell, J. D. Bowman, B. E. Crawford, P. P.J. Delheij, T. Haseyama, J. N. Knudson, L. Y. Lowie, A. Masaike, Y. Masuda, Y. Matsuda, S. Penttilä, H. Postma, N. R. Roberson, S. J. Seestrom, E. I. Sharapov, S. L. Stephenson, Y.-F. Yen and V. W. Yuan, “Parity Violation with Epithermal Neutrons,” International Conference on Nuclear Dynamics at Long and Short Distances (Angra dos Reis, Brazil, 1997), in *Nuclear Dynamics at Long and Short Distances*, H. Dias, *et al.*, Eds. (World Scientific, Singapore, 1997), p. 44.

G. E. Mitchell, J. D. Bowman, B. E. Crawford, P. P.J. Delheij, T. Haseyama, J. N. Knudson, L. Y. Lowie, A. Masaike, Y. Masuda, Y. Matsuda, S. Penttilä, H. Postma, N. R. Roberson, S. J. Seestrom, E. I. Sharapov, S. L. Stephenson, Y.-F. Yen, and V. W. Yuan, "Parity Violation with Epithermal Neutrons," 9th International Conference on Capture Gamma-Ray Spectroscopy (Budapest, Hungary, 1997), in *Proceedings of the 9th International Conference on Capture Gamma-ray Spectroscopy*, p. 616.

D. S. Montgomery, B. B. Afeyan, J. A. Cobble, J. C. Fernández, M. D. Wilke, S. H. Glenzer, R. K. Kirkwood, B. J. MacGowan, J. D. Moody, E. L. Lindman, D. H. Munro, B. H. Wilde, H. A. Rose, D. F. DuBois, B. Bezzerides, and H. X. Vu, "Evidence of Plasma Fluctuations and their Effect on the Growth of Stimulated Brillouin and Stimulated Raman Scattering in Laser Plasmas," 39th Annual Meeting of the Division of Plasma Physics of the American Physical Society (Pittsburgh, Pennsylvania, November 1997), *Physics of Plasmas* 5, 1973 (1998).

D. S. Montgomery, J. C. Fernández, M. D. Wilke, B. MacGowan, D. H. Munro, J. A. Cobble, B. H. Wilde, R. Kirkwood, J. D. Moody, and B. B. Afeyan, "Evidence of Plasma Fluctuations and their Effect on Stimulated Raman and Stimulated Brillouin Scattering," 27th Annual Anomalous Absorption Conference (Vancouver, Canada, May–June 1997).

K. R. Moore, J. R. Frigo, and M. W. Tilden, "Novel Microsatellite Control System," (San Francisco, California, December 1997).

D. V. Morgan, D. A. Platts, J. S. Shlachter, D. L. Martinez, and B. Carpenter, "Analysis of Radial Radiography for the Liner Stability Series at Pegasus: PGII-59, PGII-62, and PGII-63," 11th IEEE International Pulsed Power Conference (Baltimore, Maryland, June–July 1997), *Proceedings of the 11th IEEE International Pulsed Power Conference* 2, 1381 (1997).

K. B. Morley, C. L. Morris, J. D. Zumbro, and J. S. Sarracino, "Proof-of-Principle Demonstration of Proton Radiography on a Dynamic Object," 11th Biennial Nuclear Explosives Design Physics Conference (Livermore, California, October 1997).

C. Morris, V. Armijo, L. G. Atencio, A. Bridge, A. Gavron, G. Hart, K. Morley, T. Mottershead, G. J. Yates, and J. Zumbro, "An Integrating Image Detector for High Energy Neutrons," International Conference on Neutrons in Research and Industry (Crete, Greece, June 1996), *SPIE Proceedings* 2867, 351 (1997).

C. L. Morris, "Proton Radiography," Physics/Theoretical (P/T) Division Colloquium (Los Alamos, New Mexico, September 1997).

C. L. Morris and J. D. Zumbro, “Overview of Proton Radiography—Concepts and Techniques,” 11th Biennial Nuclear Explosives Design Physics Conference (Livermore, California, October 1997).

R. W. Moses, R. A. Gerwin, K. T. Schoenberg, and P. T. Sheehey, “Zero Dimensional Simulations of Magnetized Target Fusion on Atlas,” 39th Annual Meeting of the Division of Plasma Physics of the American Physical Society (Pittsburgh, Pennsylvania, November 1997).

J. C. Mosher, “Subspace Angles: A Metric for Comparisons in EEG and MEG,” Biomag96: Advances in Biomagnetic Research (Santa Fe, New Mexico, February 1996), *Biomag96: Advances in Biomagnetic Research* (Springer-Verlag, New York, 1997).

J. C. Mosher, C. H. Chang, and R. M. Leahy, “Comparison of the Constant and Linear Boundary Element Method for EEG and MEG Forward Modeling,” Biomag96: Advances in Biomagnetic Research (Santa Fe, New Mexico, February 1996), *Biomag96: Advances in Biomagnetic Research* (Springer-Verlag, New York, 1997).

J. C. Mosher, M. X. Huang, R. Leahy, and M. E. Spencer, “Modeling Versus Accuracy in EEG and MEG Data,” Noninvasive Functional Source Imaging (Graz, September 1997).

J. C. Mosher and R. Leahy, “Source Localization using Recursively Applied and Projected (RAP) Music,” Asilomar Conference on Signals, Systems, and Computers (Pacific Grove, California, November 1997).

C. T. Mottershead and J. D. Zumbro, “Magnetic Optics for Proton Radiography,” Particle Accelerator Conference (Vancouver, Canada, May 1997).

C. P. Munson, “Industrial Process Driven System Requirements for PSII Applications,” ATP Motor Vehicle Manufacturing Technology (Ann Arbor, Michigan, October 1997).

T. J. Murphy, “Nuclear Diagnostics for Inertial Confinement Fusion Implosions,” IEEE International Conference on Plasma Science (San Diego, California, May 1997).

T. J. Murphy and N. Delamater, “Indirect-Drive Experiments utilizing Spherical Hohlraums with Tetrahedral Illumination on OMEGA,” 27th Annual Anomalous Absorption Conference (Vancouver, Canada, May–June 1997).

T. J. Murphy and W. W. Hsing, “Experimental Plan Review for LANL SSMP Experiments ID1-FY98,” Review of SSMP Experiments (Rochester, New York, September 1997).

T. J. Murphy, J. A. Oertel, T. N. Archuleta, C. W. Barnes, R. J. Bartlett, R. R. Berggren, S. B. Boggs, S. E. Caldwell, R. E. Chrien, J. A. Cobble, B. H. Failor, J. R. Faulkner, J. C. Fernández, A. A. Hauer, G. Idzorek, J. L. Jimerson, K. A. Klare, G. A. Kyrala, R. D. Little, L. Looney, D. Montgomery, R. A. Schmell, T. J. Sedillo, W. K. Thorn, R. G. Watt, and M. D. Wilke, "Recent Diagnostic Development for Inertial Confinement Fusion Research at Los Alamos National Laboratory," 9th Topical Conference on High Temperature Plasma Diagnostics (St. Petersburg, Russia, June 1997), *Fizika Plasmy* 24, 144 (1998).

T. J. Murphy, J. A. Oertel, P. L. Gobby, G. R. Magelssen, C. Decker, R. Turner, F. J. Marshall, K. Kearney, R. Kremens, J. M. Wallace, C. W. Barnes, A. A. Hauer, O. L. Landen, L. Suter, R. Wallace, D. Bradley, R. Keck, W. Seka, K. A. Klare, N. D. Delamater, E. L. Lindman, Jr., P. Amendt, B. Hammel, R. S. Craxton, D. Harding, J. Knauer, and M. Cable, "Experiments utilizing Spherical Hohlraums with Tetrahedral Illumination on Omega," 39th Annual Meeting of the Division of Plasma Physics of the American Physical Society (Pittsburgh, Pennsylvania, November 1997).

T. J. Murphy, J. M. Wallace, N. D. Delamater, C. W. Barnes, P. Gobby, A. A. Hauer, E. L. Lindman, G. Magelssen, J. B. Moore, J. A. Oertel, R. Watt, O. L. Landen, P. Amendt, M. Cable, C. Decker, B. A. Hammel, J. A. Koch, L. J. Suter, R. E. Turner, R. J. Wallace, F. J. Marshall, D. Bradley, R. S. Craxton, R. Keck, J. P. Knauer, R. Kremens, and J. D. Schnittman, "Indirect Drive Experiments Utilizing Multiple Beam Cones in Cylindrical Hohlraums on OMEGA," 39th Annual Meeting of the Division of Plasma Physics of the American Physical Society (Pittsburgh, Pennsylvania, November 1997), *Physics of Plasmas* 5, 1960 (1998).

T. J. Murphy, J. M. Wallace, K. A. Klare, J. A. Oertel, C. W. Barnes, N. D. Delamater, A. A. Hauer, G. R. Magelssen, P. L. Gobby, O. L. Landen, S. M. Pollaine, P. Amendt, C. Decker, L. J. Suter, B. A. Hammel, R. E. Turner, R. Wallace, R. S. Craxton, F. J. Marshall, D. Bradley, D. Harding, K. Kearney, R. Keck, J. P. Knauer, R. Kremens, W. Seka, M. Cable, and J. D. Schnittman, "Indirect-Drive Experiments utilizing Spherical Hohlraums with Tetrahedral Illumination on Omega," 27th Annual Anomalous Absorption Conference (Vancouver, Canada, May–June 1997).

R. O. Nelson, J. A. Becker, D. E. Archer, L. A. Bernstein, G. D. Johns, W. S. Wilburn, W. Younes, D. M. Drake, R. S. Rundberg, S. A. Wender, K. Hauschild, S. W. Yates, and P. E. Garrett, "GEANIE at WNR/LANSCE—A New Instrument for Neutron Science," Nuclear Data for Science and Technology (Trieste, Italy, May 1997).

R. O. Nelson, G. D. Johns, W. S. Wilburn, D. M. Drake, R. S. Rundberg, D. E. Archer, J. A. Becker, L. A. Bernstein, W. Younes, K. Hauschild, G. E. Mitchell, N. R. Roberson, S. W. Yates, and P. E. Garrett,

"Performance and Status of GEANIE," American Physical Society/AAPT Meeting (Washington, D.C., April 1997).

F. Neri, H. A. Thiessen, and P. L. Walstrom, "Synchrotrons and Beamlines for Proton Radiography," Particle Accelerator Conference (Vancouver, Canada, May 1997).

A. W. Obst, D. Fulton, N. S. P. King, D. V. Morgan, D. M. Oró, D. A. Platts, D. S. Sorenson, and M. Stelts, "Performance of the Multi-Pulse X-Ray Imaging System for the Pulsed Power Hydrodynamic Experiments at LANL," 11th IEEE International Pulsed Power Conference (Baltimore, Maryland, June–July 1997), *Proceedings of the 11th IEEE International Pulsed Power Conference* 1, 448 (1997).

H. Oona, G. C. Idzorek, and J. H. Goforth, "Radiation Diagnostics and X-Ray Output from 1213 Mega-Ampere Implosions," IEEE International Conference on Plasma Science (San Diego, California, May 1997).

S. Paling, A. M. Hillas, D. Berley, S. Biller, M. L. Chen, P. Chumney, D. G. Coyne, D. Dorfan, R. A. Ellsworth, J. A. Goodman, T. J. Haines, C. M. Hoffman, L. Kelley, R. Schnee, A. Shoup, C. Sinnis, D. Williams, T. Yang, and G. B. Yodh, "Results from the CACTI Experiment: Air-Cerenkov and Particle Measurements of PeV Air Showers at Los Alamos," Cosmic Ray Conference (Durban, July 1997).

W. M. Parsons, C. C. Baldwin, E. O. Ballard, R. R. Bartsch, J. F. Benage, G. A. Bennett, D. W. Bowman, J. C. Cochrane, J. Creager, H. A. Davis, C. A. Ekdahl, R. F. Gribble, J. R. Griego, W. B. Hinckley, K. W. Hosack, R. J. Kasik, R. K. Keinigs, H. J. Kimerly, E. A. Lopez, A. Marquez, M. D. Monroe, S. A. Ney, D. D. Pierce, D. A. Platts, W. A. Reass, H. R. Salazar, G. M. Sandoval, D. W. Scudder, J. S. Shlachter, M. C. Thompson, R. J. Trainor, G. A. Valdez, R. G. Watt, G. A. Wurden, F. J. Wysocki, and S. M. Younger, "An Overview of the Atlas Pulsed-Power Systems," 11th IEEE International Pulsed Power Conference (Baltimore, Maryland, June–July 1997), *Proceedings of the 11th IEEE International Pulsed Power Conference* 1, 673 (1997).

R. R. Peterson, E. L. Lindman, Jr., N. D. Delamater, and G. R. Magelssen, "Post-shot LASNEX Simulations of Nova Smooth Beam Symmetry Experiments with Thin-Wall Hohlraums," 39th Annual Meeting of the Division of Plasma Physics of the American Physical Society (Pittsburgh, Pennsylvania, November 1997).

T. L. Peterson, G. D. Allred, B. G. Anderson, D. E. Bartram, and J. A. Garcia, "Data Acquisition Techniques for Explosive High Current Generators," 11th IEEE International Pulsed Power Conference (Baltimore, Maryland, June–July 1997), *Proceedings of the 11th IEEE International Pulsed Power Conference* 2, 1280 (1997).

J. A. Phillips and D. A. Baker, "Future Reversed-Field Pinch Experiments," 2nd International Symposium on Evaluation of Current Trends in Fusion Research (Washington, D.C., March 1997), *Proceedings of the Second International Symposium on Evaluation of Current Trends in Fusion Research* (Plenum Press, 1997).

J. A. Phillips, D. A. Baker, and R. F. Gribble, "Effect of Time Modulation of the Applied Fields on an RFP," 39th Annual Meeting of the Division of Plasma Physics of the American Physical Society (Pittsburgh, Pennsylvania, November 1997).

J. W. Phillips, R. M. Leahy, and J. C. Mosher, "MEG-Based Imaging of Focal Neuronal Current Sources," Biomag96: Advances in Biomagnetic Research (Santa Fe, New Mexico, February 1996), *Biomag96: Advances in Biomagnetic Research* (Springer-Verlag, New York, 1997).

V. V. Platonov, O. Tatsenko, A. I. Bykov, M. I. Dolotenko, J. C. Solem, C. M. Fowler, J. D. Goettee, D. G. Rickel, L. R. Veeser, M. G. Sheppard, W. Lewis, C. H. Gallegos, and B. R. Marshall, "Faraday Effect in $Cd_{0.57}Mn_{O.43}Te$ in High Magnetic Field," International Conference on Magnetism (Cairns, Australia, July 1997).

M. A. Plum, D. H. Fitzgerald, R. J. Macek, O. R. Sander, H. A. Thiessen, T.-S. Wang, and C. A. Wilkinson, "Experimental Evidence for the Los Alamos Proton Storage Ring Beam Instability," Particle Accelerator Conference (Vancouver, Canada, May 1997).

E. C. Pollacco, J. Brzychczyk, C. Volant, R. Legrain, L. Naplas, D. S. Bracken, H. Breuer, R. G. Korteling, K. Kwiatkowski, K. B. Morley, E. Renshaw-Foxford, V. E. Viola, N. R. Yoder, J. G. del Campo, and J. Cugnon, "Boiling a Nucleus," 35th International Winter Meeting on Nuclear Physics (Bormio, Italy, February 1997), in *Proceedings of 35th International Winter Meeting on Nuclear Physics*, p. 527.

Pollak, G. D., D. B. Harris, R. E. Chrien, and B. F. Failor, "Mix, Temperature, and Density Capsule Conditions in a 1-ns Square Pulse Convergence Study," 39th Annual Meeting of the Division of Plasma Physics of the American Physical Society (Pittsburgh, Pennsylvania, November 1997), *Bulletin of the American Physical Society* 42, 1841 (1997).

C. E. Ragan, B. W. Asay, B. I. Bennett, Jr., J. D. Bowman, D. J. Funk, G. L. Morgan, R. L. Rabie, and V. W. Yuan, "Shock Temperature Measurements using Neutron Resonance Spectroscopy (NRS)," 11th Biennial Nuclear Explosives Design Physics Conference (Livermore, California, October 1997).

D. M. Ranken and J. S. George, "MRIVIEW: A Software tool for Integrating Brain Structural and Functional Information," 3rd International Conference on Functional Mapping of the Human Brain (Copenhagen, Denmark, May 1997).

W. A. Reass, G. A. Bennett, D. Bowman, E. Lopez, M. Monroe, and W. Parsons, "Performance Characteristics of the Altas 60 kV, 60 kJ Plastic Capacitors," 11th IEEE International Pulsed Power Conference (Baltimore, Maryland, June–July 1997), *Proceedings of the 11th IEEE International Pulsed Power Conference* **2**, 1632 (1997).

W. A. Reass, H. A. Davis, D. Coates, and H. Schleinitz, "Continued Efforts for a 200 kV, 20 kA Radar-Like Pulser for Intense Ion Beam Processing," 11th IEEE International Pulsed Power Conference (Baltimore, Maryland, June–July 1997).

W. A. Reass, D. A. Miera, and G. A. Wurden, "Initial Design of the 60 Megawatt Rotating Magnetic Field (RMF) Oscillator System for the University of Washington 'TCS' Field Reversed Configuration Experiment," 17th IEEE/NPSS Symposium on Fusion Engineering (San Diego, California, October 1997).

W. A. Reass, G. A. Wurden, D. L. Nadel, M. E. Mauel, and G. A. Navratril, "Operational Performance of the Two Channel 10 Megawatt Feedback Amplifier System for MHD Control on the Columbia University HBT-DP Tokamak," 17th IEEE/NPSS Symposium on Fusion Engineering (San Diego, California, October 1997).

R. E. Reinovsky, B. G. Anderson, D. A. Clark, C. A. Ekdahl, R. J. Faehl, J. H. Goforth, I. R. Lindemuth, T. L. Petersen, P. T. Sheehey, L. J. Tabaka, V. K. Chernyshev, V. N. Mokhov, V. N. Buzin, O. M. Byrenkov, A. M. Bujko, V. V. Vakhruchev, S. F. Garanin, B. E. Grinevich, Y. N. Gorbachev, E. V. Gubkov, V. A. Demidov, V. I. Dudoladov, V. V. Zmushko, A. I. Kuzyaev, A. I. Kucherov, B. M. Lovyagin, Y. I. Matsev, P. N. Nizovtsev, A. A. Petrukhin, A. I. Pishurov, S. S. Sokolov, V. P. Solovjov, A. I. Startsev, and V. B. Yakubov, "HEL-1: A DEMG Based Demonstration of Solid Liner Implosions at 100 MA," 11th IEEE International Pulsed Power Conference (Baltimore, Maryland, June–July 1997), *Proceedings of the 11th IEEE International Pulsed Power Conference* **1**, 378 (1997).

D. J. Rej, H. A. Davis, J. C. Olson, G. E. Remnev, A. N. Zakoutaev, V. A. Ryzhkov, V. K. Struts, I. F. Isakov, V. A. Shulov, N. A. Nochevnaya, R. Stinnett, E. L. Neau, K. Yatsui, and W. Jiang, "Materials Processing with Intense Pulsed Ion Beams," 43rd National Symposium of the American Vacuum Society (Philadelphia, Pennsylvania, October 1996), *Journal of Vacuum Science and Technology A* **15**, 1089 (1997).

D. C. Rislove, H. C. Bryant, M. Gulley, C. E. M. Strauss, D. J. Funk, W. A. Miller, X. M. Zhao, A. Stintz, G. A. Kyrala, and W. B. Ingalls, "Isotope-Dependent Effects in an Autodetaching Resonance in H^-," Physics of Electronic and Atomic Collisions (Vienna, Switzerland, July 1997).

D. C. Rislove, H. C. Bryant, W. A. Miller, A. Stintz, X. M. Zhao, M. Gulley, D. J. Funk, C. E. M. Strauss, G. A. Kyrala, and W. B. Ingalls, "Resonant Two-Photon Detachment in Negative Hydrogen Ions," American Physical Society/AAPT Meeting (Washington, D.C., April 1997).

B. R. Rusnak, W. B. Haynes, K.-C. D. Chan, R. C. Gentzlinger, R. B. Kidman, N. S. P. King, R. E. Lujan, M. Maloney, S. Ney, A. H. Shapiro, J. L. Ullmann, A. Hanson, and H. Sefa, "In-Situ Proton Irradiation and Measurement of Superconducting RF Cavities under Cryogenic Conditions," Particle Accelerator Conference (Vancouver, Canada, May 1997).

G. J. Sadler, J. M. Adams, C. W. Barnes, P. Batistoni, N. Watkins, L. C. Johnson, F. B. Marcus, M. J. Loughlin, A. L. Roquemore, D. Bond, N. Hawkes, O. N. Jarvis, and P. van Belle, "Calibration Issues for Neutron Diagnostics," Diagnostics for Thermonuclear Reactors (Varenna, Italy, September 1997).

V. D. Sandberg, "LSND Data Acquisition," IEEE/Real Time Conference (Beaune, France, September 1997).

D. M. Schmidt and J. S. George, "A Method for Calculating Regions Containing Neural Activation at a Given Confidence Level from MEG Data," Biomag96: Advances in Biomagnetic Research (Santa Fe, New Mexico, February 1996), *Biomag96: Advances in Biomagnetic Research* (Springer-Verlag, New York, 1997).

D. M. Schmidt, J. S. George, and C. C. Wood, "Estimating Active Regions of Variable Extent from MEG Data," 3rd International Conference on Functional Mapping of the Human Brain (Copenhagen, Denmark, May 1997).

K. T. Schoenberg, C. W. Barnes, J. C. Fernández, A. A. Hauer, W. W. Hsing, R. A. Kopp, and S. A. Letzring, "Physics Mission and Objectives of the Trident Upgrade Laser," 39th Annual Meeting of the Division of Plasma Physics of the American Physical Society (Pittsburgh, Pennsylvania, November 1997).

D. W. Scudder, K. W. Hosack, W. M. Parsons, W. A. Reass, M. C. Thompson, F. J. Wysocki, and J. Creager, "Controls and Data Acquisition on Atlas," 11th IEEE International Pulsed Power Conference (Baltimore, Maryland, June–July 1997), *Proceedings of the 11th IEEE International Pulsed Power Conference* 2, 1285 (1997).

S. J. Seestrom, “Initial Testing of an Ultra-Cold Neutron Source at Los Alamos,” American Physical Society/AAPT Meeting (Washington, D.C., April 1997).

S. J. Seestrom, T. J. Bowles, T. O. Brun, R. E. Hill, and C. L. Morris, “Initial Testing of an Ultra-Cold Neutron Source at Los Alamos,” 4th International Seminar on Neutron-Nucleus Interactions (Dubna, Russia, May 1997).

S. J. Seestrom, T. J. Bowles, R. Hill, G. L. Greene, and C. L. Morris, “Development of an Ultra-Cold Neutron Source at MLNSC,” International Conference on Neutrons in Research and Industry (Crete, Greece, June 1997), *SPIE Proceedings* 2867, 521 (1997).

S. J. Seestrom, T. J. Bowles, R. E. Hill, G. L. Greene, and C. L. Morris, “Development of an Ultracold Neutron Source at the Los Alamos Neutron Science Center,” Nuclear Data for Science and Technology (Trieste, Italy, May 1997).

S. J. Seestrom, J. D. Bowman, B. E. Crawford, P. P. J. Delheij, T. Haseyama, J. N. Knudson, L. Y. Lowie, A. Masaike, Y. Matsuda, G. E. Mitchell, N. R. Roberson, S. Penttilä, Yu. P. Popov, H. Postma, E. I. Sharapov, S. Stephenson, Y.-F. Yen, and V. Yuan, “Study of Parity Nonconservation with Epithermal Neutrons,” International Conference on Neutrons in Research and Industry (Crete, Greece, June 1997), *SPIE Proceedings* 2867, 388 (1997).

G. S. Selwyn, “Contamination Control for Plasma Tools and Semiconductor Processes,” Contamination, its Measurement, and Control in Vacuum Systems (Newport News, Virginia, March 1997).

G. S. Selwyn, “New Developments and Opportunities for In-Situ Imaging and Control of Particulate Contamination in Plasma Processing,” Dusty Plasmas (Cambridge, England, May 1997).

G. S. Selwyn, “Real-Time Visualization of the Physics and Chemistry of Particulate Contamination in Plasma and Materials Processing,” ASM Conference on Materials Processing (Amsterdam, Netherlands, October 1997).

G. S. Selwyn, I. Henins, J. Jeong, S. Babayan, and R. Hicks, “High Rate Cleaning of Surfaces using Atmospheric Pressure Generation of Reactive Metastable Species,” American Vacuum Society (San Jose, California, October 1997).

G. S. Selwyn and W. Welch, “In-Situ Detection and Removal of Particulate Contamination by Plasma Processing,” Electrochemical Society Meeting (Montreal, Canada, May 1997).

W. R. Shanahan, M. S. Murillo, and J. F. Benage, Jr., “Simulation of a Strongle Coupled Plasma Experiment,” 11th Biennial Nuclear Explosives Design Physics Conference (Livermore, California, October 1997).

P. T. Sheehey, R. J. Faehl, J. A. Guzik, R. C. Kirkpatrick, I. R. Lindemuth, R. A. Gerwin, R. W. Moses, R. E. Reinovsky, and F. J. Wysocki, “Magnetized Target Fusion Research at Los Alamos National Laboratory,” 11th Biennial Nuclear Explosives Design Physics Conference (Livermore, California, October 1997).

P. T. Sheehey, R. A. Gerwin, R. C. Kirkpatrick, I. R. Lindemuth, R. W. Moses, and F. J. Wysocki, “Computational Modeling of Wall-Supported Dense Z-Pinches,”Dense Z-Pinches (Vancouver, Canada, May 1997).

P. T. Sheehey, R. A. Gerwin, R. C. Kirkpatrick, I. R. Lindemuth, and F. J. Wysocki, “Computational Modeling of Wall-Supported Dense Z-Pinches,” IEEE International Conference on Plasma Science (San Diego, California, May 1997).

P. T. Sheehey, R. A. Gerwin, R. C. Kirkpatrick, I. R. Lindemuth, and F. J. Wysocki, “Computational Modeling of Wall-Supported Dense Z-Pinches,” Innovative Confinement Concepts Workshop (Marina del Rey, California, March 1997).

M. G. Sheppard, W. L. Atchison, W. E. Anderson, R. J. Bartlett, J. H. Brownell, K. R. Calahan, C. A. Ekdahl, G. A. Erickson, C. M. Fortgang, R. D. Fulton, R. A. Gore, C. R. Hall, D. V. Morgan, H. Oona, D. M. Oró, J. P. Roberts, G. Rodriguez, L. E. Rohlev, L. D. Sanders, J. L. Stokes, J. B. Stone, J. K. Studebaker, A. Taylor, R. J. Trainor, D. Winske, B. L. Wright, R. R. Bartsch, J. C. Cochrane, and W. L. Coulter, “Rayleigh-Taylor Mix Experiment on Pegasus,” 11th Biennial Nuclear Explosives Design Physics Conference (Livermore, California, October 1997).

M. G. Sheppard, W. L. Atchison, W. E. Anderson, R. J. Bartlett, J. H. Brownell, K. R. Calahan, C. A. Ekdahl, G. A. Erickson, C. M. Fortgang, R. D. Fulton, R. A. Gore, C. R. Hall, D. V. Morgan, H. Oona, D. M. Oró, J. P. Roberts, G. Rodriguez, L. E. Rohlev, L. D. Sanders, J. L. Stokes, J. B. Stone, J. K. Studebaker, A. Taylor, R. J. Trainor, D. Winske, B. L. Wright, R. R. Bartsch, J. C. Cochrane, and W. L. Coulter, “Rayleigh-Taylor Mix Experiment on Pegasus,” 11th IEEE International Pulsed Power Conference (Baltimore, Maryland, June–July 1997), *Proceedings of the 11th IEEE International Pulsed Power Conference* 2, 1399 (1997).

J. S. Shlachter, P. J. Adams, W. L. Atchison, R. R. Bartsch, J. F. Benage, J. C. Cochrane, W. L. Coulter, C. A. Ekdahl, R. J. Faehl, R. D. Fulton, J. Guzik, D. Holtkamp, M. E. Jones, R. Keinigs, N. S. P. King, G. A. Kyrala, H. Lee, I. R. Lindemuth, D. V. Morgan, R. W. Moses,

A. W. Obst, H. Oona, D. Oró, W. M. Parsons, D. Platts, R. E. Reinovsky, G. Rodriguez, D. W. Scudder, M. Sheppard, D. S. Sorenson, J. L. Stokes, A. Taylor, R. J. Trainor, R. G. Watt, and G. A. Wurden, “Pegasus II Experiments and Plans for the Altas Pulsed Power Facility,” 11th IEEE International Pulsed Power Conference (Baltimore, Maryland, June–July 1997), *Proceedings of the 11th IEEE International Pulsed Power Conference* 1, 361 (1997).

V. A. Shulov, N. A. Nochovanya, V. A. Kocheev, L. G. Polyakova, E. V. Fedorova, G. E. Remnev, I. F. Isakov, D. J. Rej, H. A. Davis, M. A. Nastasi, and K. C. Walter, “Crater Formation during Intense Ion Beam Surface Treatment,” Surface Modification of Metals by Ion Beams (Gatlinburg, Tennessee, September 1997).

R. E. Siemon, C. A. Ekdahl, Jr., I. R. Lindemuth, R. E. Reinovsky, and K. T. Schoenberg, “Magnetized Target Fusion: Principles and Status,” 39th Annual Meeting of the Division of Plasma Physics of the American Physical Society (Pittsburgh, Pennsylvania, November 1997).

J. Simon-Gillo, “Deuteron and Anti-Deuteron Production in Heavy-Ion Collisions,” Physics and Astrophysics of Quark Gluon Plasma (Jaipur, India, March 1997).

D. P. Smitherman, R. E. Chrien, N. M. Hoffman, and G. R. Magelssen, “Modeling of Feed-Out Instability in Nova Experiments,” 39th Annual Meeting of the Division of Plasma Physics of the American Physical Society (Pittsburgh, Pennsylvania, November 1997), *Bulletin of the American Physical Society* 42, *1953* (1997).

D. S. Sorenson, B. Carpenter, N. S. P. King, D. Morgan, A. W. Obst, D. Platts, P. Rodriguez, J. Roberts, M. Stelts, J. Stokes, T. Taylor, L. Veeser, B. C. Frogget, R. M. Malone, T. W. Tunnell, D. T. Westley, W. B. Broste, and R. Flurer, “Ejecta Experiments at the Pegasus Pulsed Power Facility,” 11th IEEE International Pulsed Power Conference (Baltimore, Maryland, June–July 1997), *Proceedings of the 11th IEEE International Pulsed Power Conference* 2, 1387 (1997).

M. E. Spencer, R. M. Leahy, and J. C. Mosher, “A Skull-Based Multiple Dipole Phantom for EEG and MEG Studies,” Biomag96: Advances in Biomagnetic Research (Santa Fe, New Mexico, February 1996), *Biomag96: Advances in Biomagnetic Research* (Springer-Verlag, New York, 1997).

J. L. Stokes, J. A. Guzik, and P. J. Adams, “Disrupted Hydrodynamics Experiments on Pegasus,” 11th Biennial Nuclear Explosives Design Physics Conference (Livermore, California, October 1997).

F. J. Swenson, R. E. Chrien, B. H. Wilde, D. L. Peterson, W. Matuska, G. Idzorek, W. E. Anderson, J. L. Porter, R. Spielman, C. Deeney, G. A. Chandler, and D. L. Fehl, “Early Results From Integrated AGEX on

the Z Machine," 11th Biennial Nuclear Explosives Design Physics Conference (Livermore, California, October 1997).

J. J. Szymanski, W. M. Snow, J. D. Bowman, B. Cain, B. E. Crawford, P. P. J. Delheij, R. D. Hartman, T. Haseyama, C. D. Keith, J. N. Knudson, A. Komives, M. Leuschner, L. Y. Lowie, A. Masaike, Y. Matsuda, G. E. Mitchell, S. I. Penttilä, H. Postma, D. Rich, N. R. Roberson, S. J. Seestrom, E. Sharapov, S. L. Stephenson, Y.-F. Yen, and V. W. Yuan, "Parity Violation in Neutron Transmission in Xenon," 4th International Seminar on Neutron-Nucleus Interactions (Dubna, Russia, 1997), in *Proceedings of the Forth International Seminar on Neutron-Nucleus Interactions* (JINR, Dubna, 1997), p. 113.

H. A. Thiessen, "Overview from Los Alamos: Current Thinking on RF Upgrade Issues," Particle Accelerator Conference (Vancouver, Canada, May 1997).

H. A. Thiessen, F. Neri, K. R. Rust, and D. B. Redd, "Multi-Pulse Extraction from Los Alamos Proton Storage Ring for Radiographic Applications," Particle Accelerator Conference (Vancouver, Canada, May 1997).

M. C. Thompson, K. W. Hosack, and D. W. Scudder, "Optically Based Remote Sensor-Transponder for the Atlas Capacitor Bank Monitoring and Control System," 11th IEEE International Pulsed Power Conference (Baltimore, Maryland, June–July 1997).

M. W. Tilden, "Coodinated Covert Detector Ecologies," 4th European Conference on Artificial Life (Brighton, United Kingdom, July 1997), in *Proceedings of the 4th European Conference on Artificial Life*, P. Husbands and I. Harvey, Eds. (MIT Press/Bradford Books, 1997).

M. W. Tilden, J. R. Frigo, and K. R. Moore, "Novel Microsatellite Control System," International Workshop on Applications of Neural Networks to Telecommunications (Melbourne, Australia, June 1997).

R. J. Trainor, J. F. Benage, Jr., J. A. Guzik, and P. J. Adams, "Pegasus/Atlas Experiment Design for Secondary Weapons Physics," 11th Biennial Nuclear Explosives Design Physics Conference (Livermore, California, October 1997).

R. J. Trainor, W. M. Parsons, E. O. Ballard, R. R. Bartsch, J. F. Benage, G. A. Bennett, R. L. Bowers, D. W. Bowman, J. H. Brownell, J. C. Cochrane, H. A. Davis, C. A. Ekdahl, R. D. Fulton, R. F. Gribble, J. R. Griego, J. Guzik, M. E. Jones, W. B. Hinckley, K. W. Hosack, R. J. Kasik, R. Keinigs, H. Lee, E. A. Lopez, I. R. Lindemuth, M. D. Monroe, R. W. Moses, D. Oró, S. A. Ney, D. D. Pierce, D. Platts, W. A. Reass, R. E. Reinovsky, G. Rodriguez, H. R. Salazar, G. M. Sandoval, D. W. Scudder, M. Sheppard, J. S. Shlachter, A. Taylor, M. C. Thompson, G. A. Valdez, R. G. Watt, and G. A. Wurden, “Overview of the Atlas Project,” 11th IEEE International Pulsed Power Conference (Baltimore, Maryland, June–July 1997), *Proceedings of the 11th IEEE International Pulsed Power Conference* 1, 37 (1997).

R. J. Trainor, J. S. Shlachter, J. F. Benage, Jr., D. W. Scudder, and W. M. Parsons, “Applications of the Atlas Pulsed Power Facility,” 11th IEEE International Pulsed Power Conference (Baltimore, Maryland, June–July 1997).

D. L. Tubbs, N. M. Hoffman, J. B. Beck, and C. W. Barnes, “Direct-Drive Targets for Cylindrical Implosions Experiments,” 27th Annual Anomalous Absorption Conference (Vancouver, Canada, May–June 1997).

Tubbs, D. L., N. M. Hoffman, J. B. Beck, and C. W. Barnes, “Direct-Drive Targets for Cylindrical Implosion Experiments,” 39th Annual Meeting of the Division of Plasma Physics of the American Physical Society (Pittsburgh, Pennsylvania, November 1997).

T. W. Tunnell, R. M. Malone, R. H. Frederickson, A. D. DeLanoy, D. E. Johnson, C. A. Ciarcia, and D. S. Sorenson, “Deriving Particle Distributions from In-Line Fraunhofer Holographic Data,” Signal and Data Processing of Small Targets (San Diego, California, July 1997), *SPIE Proceedings* 3163, 558 (1997).

H. W. van Hecke, “Determining Freezeout Temperatures in Relativistic Heavy-Ion Collisions,” American Chemical Society (Las Vegas, Nevada, September 1997).

H. van Hecke, J. P. Sullivan, J. R. Nix, D. D. Strottman, and B. R. Schlei, “Extracting Hydrodynamic Parameter Values from 158 GeV/c Pb+Pb Collision Data,” Ultra-Relativistic Nucleus-Nucleus Collisions (Tsukuba, Japan, December 1997).

L. R. Veeser, C. A. Ekdahl, Jr., H. Oona, P. J. Rodriguez, J. C. Solem, S. M. Younger, W. Lewis, W. D. Turley, A. I. Bykov, V. V. Aseeva, G. V. Boriskov, M. I. Dolotenko, N. I. Egorov, N. P. Kolokol’Chikov, Y. P. Kuropatkin, V. D. Mironenko, V. N. Pavlov, and A. A. Volkov, “Isentropic Compression of Argon using Pulsed Power,” 11th IEEE International Pulsed Power Conference (Baltimore, Maryland, June–July 1997), *Proceedings of the 11th IEEE International Pulsed Power Conference* 1, 384 (1997).

J. M. Veilleux, M. S. El-Genk, E. P. Chamberlin, C. Munson, and J. Fitzpatrick, “Plasma Decontamination of Uranium Oxide from Stainless Steel Surfaces,” American Nuclear Society 1997 Winter Meeting (Albuquerque, New Mexico, November 1997), *Transactions of the American Nuclear Society* 77, 120 (1997).

V. E. Viola, K. Kwiatkowski, W.-C. Hsi, G. Wang, D. S. Bracken, H. Breuer, Y. Y. Chu, E. Cornell, F. Gimeno-Nogues, D. S. Ginger, S. Gushue, M. J.Huang, R. G. Korteling, W. G. Lynch, K. B. Morely, E. Ramakrishnan, L. P. Remsberg, D. Rowland, M. B. Tsang, V. E. Viola, S. J. Yennello, N. R. Yoder, and H. Xi, "Heating the Nuclear Liquid with GeV Hadrons," 8th International Conference on Nuclear Reaction Mechanisms (Varenna, Italy, June 1997), in *Proceedings of 8th International Conference on Nuclear Reaction Mechanisms*, p. 198.

H. Wagner, R. W. Moses, and K. F. Schoenberg, "Industrial Magnetoplasmadynamic Processing Tool," American Chemical Society Metallurgical Coatings and Thin Films (San Diego, California, April 1997).

P. J. Walsh, S. C. Evans, G. T. Schappert, and G. A. Kyrala, "MCP Characterization at the Cu and Mo Kα X-Ray Energies," Ultrahigh- and High-Speed Photography and Image-Based Motion Measurement (San Diego, California, July 1997), *SPIE Proceedings* 3173, 214 (1997).

K. C. Walter, M. A. Nastasi, C. P. Munson, J. T. Scheuer, B. P. Wood, J. R. Conrad, K. Sridharan, S. Malik, and R. A. Breun, "Advances in Plasma Source Ion Implantation Techniques for Surface Modification," Surface Modification of Metals by Ion Beams (Gatlinburg, Tennessee, September 1997).

R. G. Watt, "Experimental Uses of X-Ray Backlighting in High-Energy Density Physics," Altas Diagnostic Workshop (Santa Barbara, California, May 1997).

R. G. Watt, J. R. Duke, N. E. Elliot, P. L. Gobby, R. V. Hollis, R. A. Kopp, R. J. Mason, G. Pollak, D. C. Wilson, T. R. Boehly, D. D. Meyerhofer, J. P. Knauer, C. P. Verdon, O. Willi, R. J. Taylor, and D. H. Kalantar, "Recent Results from the Foam-Buffered Direct Drive Experiment," 27th Annual Anomalous Absorption Conference (Vancouver, Canada, May–June 1997).

R. G. Watt, J. R. Duke, N. E. Elliott, P. L. Gobby, R. V. Hollis, O. Willi, R. A. Kopp, R. J. Mason, G. D. Pollak, D. C. Wilson, C. P. Verdon, D. H. Kalantar, T. R. Boehly, J. P. Knauer, and D. D. Meyerhofer, "Rayleigh-Taylor Growth and Imprint Reduction Using Foam Buffer Layers on the Omega Laser," 39th Annual Meeting of the Division of Plasma Physics of the American Physical Society (Pittsburgh, Pennsylvania, November 1997).

D. H. White, "LSND Neutrino Oscillation Results," Electroweak Interactions and Unified Theories Conference (Les Arcs, March 1997).

D. H. White, Z. Ajduk, and A. K. Wroblewski, "LSND Neutrino Oscillation Results," 28th International Conference on High-Energy Physics (Warsaw, Poland, July 1996).

W. S. Wilburn, D. M. Drake, G. D. Johns, R. O. Nelson, D. E. Archer, J. A. Becker, L. A. Bernstein, W. Younes, G. E. Mitchell, N. R. Roberson, and J. F. Shriver, "Level Structure Studies with the GEANIE Detector," American Physical Society/AAPT Meeting (Washington, D.C., April 1997).

W. S. Wilburn, G. E. Mitchell, N. R. Roberson, and J. F. Shriner, Jr., "Techniques for Precision Measurements of Parity Violating Asymmetries," AIP Conference on Application of Accelerators in Research and Industry, *AIP Conference Proceedings* 392, 297 (1997).

B. H. Wilde, F. J. Swenson, and R. E. Chrien, "Weapons Physics Experiments for the Sandia Z Machine," 11th Biennial Nuclear Explosives Design Physics Conference (Livermore, California, October 1997).

C. A. Wilkinson, B. Blind, D. H. Fitzgerald, R. J. Macek, F. Neri, M. A. Plum, O. R. Sander, and H. A. Thiessen, "Comparison of Beam Transport Simulations to Measurements at the Los Alamos Proton Storage Ring," Particle Accelerator Conference (Vancouver, Canada, May 1997).

D. C. Wilson, C. J. Fontes, G. D. Pollak, J. Abdallah, Jr., P. D. Goldstone, and J. A. Cobble, "Non-LTE Effects on X-Ray Emission from Laser Irradiated Gold Shells," 39th Annual Meeting of the Division of Plasma Physics of the American Physical Society (Pittsburgh, Pennsylvania, November 1997).

D. C. Wilson, G. D. Pollak, C. J. Fontes, J. Abdallah, Jr., P. D. Goldstone, J. A. Cobble, S. R. Goldman, and P. Jaanimagi, "Non-LTE Effects on X-Ray Emission from Laser Irradiated Gold Spheres," 27th Annual Anomalous Absorption Conference (Vancouver, Canada, May–June 1997).

D. Winske, G. S. Selwyn, and M. Rosenberg, "Low Frequency Waves in a Dusty Plasma Crystal," 39th Annual Meeting of the Division of Plasma Physics of the American Physical Society (Pittsburgh, Pennsylvania, November 1997).

B. P. Wood, S. D. Soderquist, A. Gurevich, J. Steele, F. Hampel, K. C. Walter, A. J. Perry, and J. Treglio, "Plasma-Produced Erbia Coatings for Waste Reduction in Plutonium Casting Operations," IEEE International Conference on Plasma Science (San Diego, California, May 1997).

B. P. Wood, S. D. Soderquist, K. M. Vigil, T. N. Taylor, T. Abeyta, A. Gurevitch, J. H. Steele, Jr., F. G. Hampel, K. C. Walter, and J. R. Treglio, "Cathodic-Arc Deposited Erbia for Molten Plutonium Containment in Casting Operations," Plutonium Futures—The Science (Santa Fe, New Mexico, August 1997).

B. P. Wood, T. N. Taylor, and K. C. Walter, “Plasma Source Ion Implantation to Increase the Adhesion of Subsequently Deposited Coatings,” Applied Plasma Science (Los Angeles, California, September 1997).

B. P. Wood, J. R. Treglio, A. J. Perry, A. Elkind, and H. E. Jetton, “Erbia Coatings to Contain Molten Plutonium,” American Chemical Society Metallurgical Coatings and Thin Films (San Diego, California, April 1997).

B. P. Wood, M. G. Tuszewski, D. Pesenson, and F. Wessel, “Cathodic Arc Plasma Density and Profile Measurements,” Council on Undergraduate Research (Washington, D.C., April 1997).

B. P. Wood, M. Tuszewski, D. Pesensen, and F. J. Wessel, “Cathodic Arc Plasma Density and Profile Measurement,” IEEE International Conference on Plasma Science (San Diego, California, May 1997).

J. Workman, T. Tierney, G. A. Kyrala, and J. F. Benage, Jr., “Dense Aluminum Plasma Equation of State Measurements,” 39th Annual Meeting of the Division of Plasma Physics of the American Physical Society (Pittsburgh, Pennsylvania, November 1997).

G. Wurden, “Active Control of 2/1 Magnetic Island in the HBT-EP Tokamak,” APS Division of Plasma Physics (Pittsburg, Pennsylvania, November 1997).

G. A. Wurden, “State of the Art in Bolometry on Large Fusion Devices,” International School of Plasma Physics “Piero Caldirola” (Varenna, Italy, September 1997).

G. A. Wurden, H. A. Davis, A. Taylor, D. Bowman, E. Ballard, S. Ney, D. Scudder, and R. J. Trainor, “Atlas Chamber, Power Flow Channel, and Diagnostic Interface Design,” 11th IEEE International Pulsed Power Conference (Baltimore, Maryland, June–July 1997), *Proceedings of the 11th IEEE International Pulsed Power Conference* 2, 1291 (1997).

G. A. Wurden and B. J. Peterson, “Imaging Bolometry Development for Large Fusion Devices,” International School of Plasma Physics “Piero Caldirola” (Varenna, Italy, September 1997).

F. J. Wysocki, R. E. Chrien, G. Idzorek, H. Oona, D. O. Whiteson, R. C. Kirkpatrick, I. R. Lindemuth, and P. T. Sheehey, “Progress with Developing a Target for Magnetized Target Fusion,” 11th IEEE International Pulsed Power Conference (Baltimore, Maryland, June–July 1997), *Proceedings of the 11th IEEE International Pulsed Power Conference* 2, 1393 (1997).

F. J. Wysocki, R. E. Chrien, G. Idzorek, H. Oona, D. O. Whiteson, R. C. Kirkpatrick, I. R. Lindemuth, and P. T. Sheehey, “Progress with Developing a Target for Magnetized Target Fusion,” IEEE International Conference on Plasma Science (San Diego, California, May 1997).

G. J. Yates, N. S. P. King, and T. E. McDonald, “High Speed Intensified Shuttered Multi-Port CCD Camera,” 43rd International Instrumentation Symposium (Orlando, Florida, May 1997).

V. Yuan, “Compound-Nuclear Neutron Resonances for Fundamental and Applied Physics: from Parity Violation to Dynamic Temperature Measurements,” Meeting of the Division of Nuclear Physics of the American Physical Society (Whistler, Canada, October 1997).

V. Yuan, “Neutron Resonances in Compound Nucleus: Parity Conservation to Dynamic Temperature Measurements,” International Symposium on Trends in Subatomiuc Physics (Taipei, Taiwan, August 1997).

V. W. Yuan, “Neutron Resonances in the Compound Nucleus: Parity Nonconservation to Dynamic Temperature Measurements,” Physics Since Parity Symmetry Breaking (Nanjing, Peoples’ Republic of China, August 1997), in *Physics Since Parity Symmetry Breaking* (World Scientific, Singapore, 1998), p. 19.

V. W. Yuan, B. W. Asay, R. M. Boat, J. D. Bowman, D. J. Funk, R. S. Hixson, L. M. Hull, G. W. Laabs, R. K. London, G. L. Morgan, C. E. Ragan, and R. L. Rabie, “Dynamic Temperature and Velocity Measurements using Neutron Resonance Spectroscopy,” Nuclear Data for Science and Technology (Trieste, Italy, May 1997), in *Proceedings of the Italian Physical Society* 59, 1723 (1997).

1998 Conferences

K. L. Albright, R. C. Smith, C. Ho, K. S. Wilson, J. M. Bradley, A. Bird, D. E. Casperson, M. A. Hindman, R. M. Whitaker, J. Theiler, R. W. Scarlett, and W. C. Priedhorsky, “A Photon Counting Imager,” Detection and Analysis of Subsurface Objects and Phenomena (Monterey, California, October 1998).

W. L. Atchison, R. J. Faehl, R. E. Reinovsky, and D. Morgan, “Studies of Solid Liner Stability in Electromagnetic Implosions,” International Conference on Plasma Science (ICOPS) (Raleigh, North Carolina, June 1998), abstract in *Abstracts from the 1998 IEEE International Conference on Plasma Science*, 246 (1998).

D. Baker, “Behavior of Reverse-Field Pinches,” 40th Annual Meeting of the Division of Plasma Physics of the American Physical Society (New Orleans, Louisiana, November 1998).

C. W. Barnes, D. L. Tubbs, J. B. Beck, J. A. Oertel, N. Shambo, S. A. Voss, R. G. Watt, T. R. Boehly, D. K. Bradley, and J. P. Knauer, “Direct-Drive Cylindrical Implosions on the OMEGA Laser,” 40th Annual Meeting of the Division of Plasma Physics of the American Physical Society (New Orleans, Louisiana, November 1998).

C. W. Barnes, D. L. Tubbs, N. M. Hoffman, K. A. Klare, J. A. Oertel, R. G. Watt, T. R. Boehly, D. K. Bradley, and J. P. Knauer, “Experimental Configuration of Direct Drive Cylindrical Implosions on the Omega Laser,” 12th Topical Conference High Temperature Plasma Diagnostics (Princeton, New Jersey, June 1998).

R. Bartlett, "Multi-Laboratory Calibration Facility Proposal," 2nd National Ignition Facility Diagnostics Program Workshop (Jackson Hole, Wyoming, February 1998).

R. R. Bartsch, D. A. Clark, D. Morgan, W. Anderson, H. Lee, R. Bowers, L. Veeser, W. Atchison, H. Oona, J. Stokes, J. C. Cochrane, and W. Broste, “Composite Liner, Multi-Megabar Shock Driver Development,” International Conference on Plasma Science (ICOPS) (Raleigh, North Carolina, June 1998), abstract in *Abstracts from the 1998 IEEE International Conference on Plasma Science*, 243 (1998).

R. R. Bartsch, H. Lee, D. Holtkamp, B. Wright, J. Stokes, D. Morgan, W. Anderson, and W. Broste, “Imploding Liner Material Strength Measurements at High-Strain and High Strain Rate,” 8th International Conference on Megagauss Magnetic Field Generation and Related Topics (Tallahassee, Florida, October 1998).

R. R. Bartsch and J. Stokes, “Results of Recent Pulsed Power Experiments (on the LANL Pegasus-11 Facility) Relating to Primaries,” JOWOG 32-P (Joint United States/United Kingdom Working Group) (Livermore, California, March 1998).

J. Benage, G. Kyrala, J. Workman, and T. Tierney, “Preliminary Measurements of the EOS of a Dense, Strongly Coupled Aluminum Plasma,” International Workshop on the Physics of Nonideal Plasmas (Rostock, Germany, September 1998).

M. J. Bennett, “Overview of RHIC Experiments and Accelerator,” Division of Nuclear Physics Workshop on Heavy-Ion Physics with the Relativistic Heavy Ion Collider (Santa Fe, New Mexico, October 1998).

M. J. Bennett, “Physics with Relativistic Heavy Ions: Recent Results and Experimental Outlook,” Workshop on Perturbative and Non-Perturbative Aspects of the Standard Model (Santa Fe, New Mexico, July 1998).

M. J. Bennett, *et al.* (E878 Collaboration), "Low Pt Particle Spectra and Strangelet Search from Au + Au Collisions: Final Results from BNL-AGS Experiment E878," 14th Winter Workshop on Nuclear Dynamics (Snowbird, Utah, January 1998), in *Advances in Nuclear Dynamics 4*, W. Bauer and H.-G. Ritter, Eds. (Plenum Press, 1998), p. 55.

M. J. Bennet, *et al.* (PHENIX Collaboration), "Measuring Global Observables with PHENIX," Particle Distributions in Hadronic and Nuclear Collisions Workshop (Chicago, Illinois, June 1998), in *Particle Distributions in Hadronic and Nuclear Collisions* (World Scientific, 1999).

M. J. Bennett, *et al.* (PHENIX MVD Group), "The PHENIX Multiplicity and Vertex Detector," Joint American Physical Society/American Association of Physics Teachers Meeting (Columbus, Ohio, April 1998).

J. R. Berendzen, G. S. Waldo, M. S. Park, J. Newman, T. C. Terwilliger, J. L. Perry, E. Marcotte, D. Cascio, T. Thai, M. Balbirnie, E. A. Toth, M. J. Thompson, D. Fischer, S. Griffith, T. O. Yeates, J. Bowie, R. Clubb, and D. Eisenberg, "Structural Proteomics of a High-Temperature Archeaon," Protein Society Annual Meeting (San Diego, California, July 1998).

E. D. Best, D. M. Ranken, J. C. Mosher, J. S. George, M. X. Huang, and C. J. Aine, "MEGAN: A Software Package for MEG and EEG," Functional Mapping of the Human Brain (Montreal, Canada, June 1998), abstract in *Neuroimage* 7, 797 (1998).

W. T. Buttler, R. H. Hughes, P. Kwiat, S. Lamoreaux, Luther, Morgan, Nordholt, Peterson, Simmons, and White, "Practical Quantum Cryptography in Free-Space," International Quantum Electronics Conference (San Francisco, California, May 1998).

S. E. Caldwell, S. R. Goldmann, M. D. Wilke, W. W. Hsing, G. T. Schappert, D. C. Wilson, S. B. Boggs, S. C. Evans, T. J. Sedillo, P. J. Walsh, H. Bush, P. L. Gobby, V. M. Gomez, J. E. Moore, D. J. Thomas, and L. J. Salzer, "Shock Front Evolution Near Joints and Defects," JOWOG 37 (Joint United States/United Kingdom Working Group) (Los Alamos, New Mexico, February 1998).

E. A. Chandler, P. Egan, J. Stokes, R. D. Fulton, N. King, D. Morgan, A. Obst, H. Oona, D. Oró, and D. Platts, "Material Failure and Inertial Instabilities in a Shocked and Imploded Cylindrical Aluminum Sample," International Conference on Plasma Science (ICOPS) (Raleigh, North Carolina, June 1998), abstract in *Abstracts from the 1998 IEEE International Conference on Plasma Science*, 264 (1998).

J. Chiba and J.-C. Peng, "Physics with Primary Beam," International Workshop on JHF Science (Tsukuba, Japan, March 1998), in *KEK Proceedings* 98-5, 185 (1998).

R. E. Chrien, P. L. Gobby, G. R. Magelssen, D. C. Wilson, and B. H. Wilde, "English Concept Experiments on Nova," JOWOG 37 (Joint United States/United Kingdom Working Group) (Los Alamos, New Mexico, February 1998).

R. E. Chrien, W. Matuska, Jr., F. Swenson, D. L. Peterson, G. Idzorek, B. H. Wilde, W. E. Anderson, S. P. Breeze, M. Vargas, and L. E. Ruggles, "Hole Closure Experiments and Simulations on Z," 40th Annual Meeting of the Division of Plasma Physics of the American Physical Society (New Orleans, Louisiana, November 1998).

R. E. Chrien, W. Matuska, Jr., F. Swenson, D. L. Peterson, G. Idzorek, B. H. Wilde, S. P. Breeze, M. Vargas, L. E. Ruggles, and J. Porter, "Measurements and Simulations of Diagnostic Hole Closure on Z," 12th Topical Conference High Temperature Plasma Diagnostics (Princeton, New Jersey, June 1998).

R. E. Chrien, W. Matuska, Jr., F. Swenson, D. L. Peterson, B. H. Wilde, J. Porter, S. P. Breeze, L. E. Ruggles, W. Simpson, and M. Vargas, "Measurement and Simulation of Apertures on Z Hohlraums," 12th Topical Conference High Temperature Plasma Diagnostics (Princeton, New Jersey, June 1998).

R. E. Chrien, B. H. Wilde, F. J. Swenson, D. L. Peterson, W. Matuska, D. C. Wilson, G. R. Magelssen, G. Idzorek, P. L. Gobby, and W. E. Anderson, "Integrated Experiments on Nova and Z," JOWOG 32-S (Joint United States/United Kingdom Working Group) (Aldermasten, United Kingdom, June 1998).

E. D. Church, I. Stancu, W. Strossman, G. J. VanDalen, W. Vernon, D. O. Caldwell, S. Yellin, D. Smith, R. L. Burman, J. B. Donahue, G. T. Garvey, W. C. Louis, G. B. Mills, V. Sandberg, R. Tayloe, D. H. White, R. Imlay, H. J. Kim, A. Malik, W. Metcalf, M. K. Sung, N. Wadia, K. Johnston, A. Fazely, R. M. Gunasingha, L. B. Auerbach, and R. Majkic (LSND Collaboration), "Results from LSND," Institute of Physics Annual Meeting (IOP) (London, England, March 1998).

E. D. Church, I. Stancu, W. Strossman, G. J. VanDalen, W. Vernon, D. O. Caldwell, S. Yellin, D. Smith, R. L. Burman, J. B. Donahue, G. T. Garvey, W. C. Louis, G. B. Mills, V. Sandberg, R. Tayloe, D. H. White, R. Imlay, H. J. Kim, A. Malik, W. Metcalf, M. K. Sung, N. Wadia, K. Johnston, A. Fazely, R. M. Gunasingha, L. B. Auerbach, and R. Majkic (LSND Collaboration), "Results from LSND," SLAC Summer Institute Topical Conference (Stanford, California, August 1998).

D. A. Clark, D. Morgan, and G. Rodriguez, "Pegasus Liner Stability Experiments: Diagnostics and Experimental Results," International Conference on Plasma Science (ICOPS) (Raleigh, North Carolina, June 1998), abstract in *Abstracts from the 1998 IEEE International Conference on Plasma Science*, 163 (1998).

M. D. Cooper and S. K. Lamoreaux, "New Ideas to Search for the Neutron Electric Dipole Moment," International Workshop on CP Violation without Strangeness (Trento, Italy, October 1998).

M. A. Espy, M. D. Cooper, S. K. Lamoreaux, R. H. Kraus Jr., A. Matlachov, and P. Ruminer, "SQUID Detectors in a New Experiment to Measure the Neutron Electron Dipole Moment," Applied Superconductivity Conference (Palm Desert, California, September 1998).

M. A. Espy, E. R. Flynn, R. H. Kraus, Jr., and A. Matlachov, "Design Preliminary Results from a High-Temperature Superconducting SQUID Milliscope used for Nondestructive Evaluation," Applied Superconductivity Conference (Palm Desert, California, September 1998).

M. A. Espy, E. R. Flynn, R. H. Kraus, Jr., and A. Matlachov, "Two Methods for a First Order Hardware Gradiometer using Two Hits SQUIDs," Applied Superconductivity Conference (Palm Desert, California, September 1998).

J. C. Fernández, J. A. Cobble, D. S. Montgomery, and M. D. Wilke, "A Comparative Study of Laser Reflectivity Versus *f* Number in Long-Scale Hohlraum Plasmas," 28th Annual Anomalous Absorption Conference (Bar Harbor, Maine, June 1998).

J. C. Fernández, J. A. Cobble, D. S. Montgomery, and M. D. Wilke, "Experimental Program to Elucidate and Control Stimulated Brillouin and Raman Backscattering in Long-Scale Plasmas," International Atomic Energy Authority Fusion Energy Conference (Yokohama, Japan, October 1998).

J. C. Fernández, J. A. Cobble, D. S. Montgomery, and M. D. Wilke, "Raman and Brillouin Laser Reflectivity Database from Long-Scale Toroidal Hohlraum Plasmas," 40th Annual Meeting of the Division of Plasma Physics of the American Physical Society (New Orleans, Louisiana, November 1998).

E. R. Flynn, R. H. Kraus, Jr., M. A. Espy, and A. Matlachov, "Design and Initial Results of a 155 Channel MEG System," Functional Mapping of the Human Brain (Montreal, Canada, June 1998).

J. R. Frigo, M. W. Tilden, "Biologically Inspired Neural Controller for an Infrared Tracking System," SPIE Symposium on Intelligent Systems and Advanced Manufacturing (Boston, Maryland, November 1998).

J. R. Frigo, M. W. Tilden, and K. R. Moore, "Biologically Inspired Neural Network Controller for an Infrared Tracking System," SPIE Symposium for Nuclear Instrumentation (Boston, Maryland, November 1998).

C. A. Gagliardi, T. C. Awes, M. E. Beddo, M. L. Brooks, C. N. Brown, J. D. Bush, T. A. Carey, T. H. Chang, W. E. Cooper, G. T. Garvey,

D. F. Geesaman, E. A. Hawker, X. C. He, L. D. Isenhower, S. B. Kaufman, D. M. Kaplan, P. N. Kirk, D. D. Koetke, G. Kyle, D. M. Lee, W. M. Lee, M. J. Leitch, N. Makins, P. L. McGaughey, J. M. Moss, B. A. Mueller, P. M. Nord, B. K. Park, V. Papavassiliou, J.-C. Peng, G. Petitt, P. E. Reimer, M. E. Sadler, J. Selden, P. W. Stankus, W. E. Sondheim, T. N. Thompson, R. S. Towell, R. E. Tribble, M. A. Vasiliev, Y. C. Wang, Z. F. Wang, J. C. Webb, J. L. Willis, D. Wise, and G. R. Young, "$\bar{d}/\bar{u}$ Asymmetry in the Nucleon Sea," INPC'98 (Paris, France, August 1998), *Nuclear Physics A* (in press).

C. A. Gagliardi, T. C. Awes, M. E. Beddo, M. L. Brooks, C. N. Brown, J. D. Bush, T. A. Carey, T. H. Chang, W. E. Cooper, G. T. Garvey, D. F. Geesaman, E. A. Hawker, X. C. He, L. D. Isenhower, S. B. Kaufman, D. M. Kaplan, P. N. Kirk, D. D. Koetke, G. Kyle, D. M. Lee, W. M. Lee, M. J. Leitch, N. Makins, P. L. McGaughey, J. M. Moss, B. A. Mueller, P. M. Nord, B. K. Park, V. Papavassiliou, J.-C. Peng, G. Petitt, P. E. Reimer, M. E. Sadler, J. Selden, P. W. Stankus, W. E. Sondheim, T. N. Thompson, R. S. Towell, R. E. Tribble, M. A. Vasiliev, Y. C. Wang, Z. F. Wang, J. C. Webb, J. L. Willis, D. Wise, G. R. Young, "$\bar{d}/\bar{u}$ Asymmetry in the Nucleon Sea," 14th International Seminar on High Energy Physics Problems (Dubna, Russia, August 1998).

G. Garvey, *et al.* (E866 Collaboration), "Large Asymmetry In the Up-Down Sea of the Nucleon," International Conference on Baryon-Meson Physics (Cracow, Poland, June 1998).

G. Garvey, *et al.* (E866 Collaboration), "Update of LSND Results on Neutrino Oscillations," International Conference on Baryon-Meson Physics (Cracow, Poland, June 1998).

G. Garvey, *et al.* (LSND and BooNE Collaborations), "Update on LSND and the Status of BooNE," European Center for Nuclear Theory Wookshop on Physics Beyond the Standard Model (Trento, Italy, April 1998).

J. S. George, D. M. Schmidt, and C. C. Wood, "Probabalistic Strategies for Multi-Modality Integration," Biomag98: Advances in Biomagnetic Research (Sendia, Japan, August 1998).

M. S. Gulley, J. J. Gomez, M. H. Holzscheiter, R. J. Hughes, D. F. V. James, P. G. Kwiat, S. K. Lamoreaux, C. G. Peterson, V. Sandberg, M. M. Schauer, C. Simmons, D. Tupa, P. Wang, and A. G. White, "Progress Towards Quantum Logic Operations with a Calcium Ion Trap," Annual Meeting of the Optical Society of America (Baltimore, Maryland, October 1998).

M. S. Gulley, J. J. Gomez, M. H. Holzscheiter, D. F. V. James, P. G. Kwiat, S. K. Lamoreaux, C. G. Peterson, V. Sandberg, M. M. Schauer, C. Simmons, D. Tupa, P. Wang, and A. G. White, and R. J. Hughes, "Progress Towards using a Calcium Ion Trap to Perform Quantum Logic

Operations," 4th International Conference on Quantum Communication, Measurement, and Computing (Evanston, Illinois, August 1998).

M. S. Gulley, R. J. Hughes, J. J. Gomez, M. H. Holzscheiter, D. F. V. James, P. G. Kwiat, S. K. Lamoreaux, C. G. Peterson, V. Sandberg, M. M. Schauer, C. Simmons, D. Tupa, P. Wang, and A. G. White, "Progress Towards Quantum Computation with an Ion Trap," Four Corners Spring Section Meeting of the American Physical Society (Albuquerque, New Mexico, April 1998).

M. S. Gulley, R. J. Hughes, J. J. Gomez, M. H. Holzscheiter, D. F. V. James, P. G. Kwiat, S. K. Lamoreaux, C. G. Peterson, V. Sandberg, M. M. Schauer, C. Simmons, D. Tupa, P. Wang, and A. G. White, "Progress Towards Quantum Computation with Trapped Calcium Ions," Meeting of the Division of Atomic, Molecular, and Optical Physics of the American Physical Society (Santa Fe, New Mexico, May 1998).

E. A. Henry, D. E. Archer, W. Younes, J. A. Becker, and R. O. Nelson, "Lu(N,Xn) Cross-Section Measurements," *Abstracts of Papers of the American Chemical Society* 216, 43 (1998).

G. E. Hogan, "PCDAQ, A Windows Based DAQ System," Fall Meeting of the Division of Nuclear Physics of the American Physical Society (Santa Fe, New Mexico, October 1998), abstract in *Bulletin of the American Physical Society* 43, 1557 (1998).

M. H. Holzscheiter, J. J. Gomez, M. S. Gulley, R. J. Hughes, D. F. V. James, P. G. Kwiat, S. K. Lamoreaux, C. G. Peterson, V. Sandberg, M. M. Schauer, C. Simmons, D. Tupa, P. Wang, and A. G. White, "Progress towards Quantum Computation with Trapped Calcium Ions," 16th International Conference on Atomic Physics (Windsor, Canada, August 1998).

M. X. Huang, J. C. Mosher, and R. Leahy, " Sensor-Weighted Multiple Sphere Head Model for MEG," Functional Mapping of the Human Brain (Montreal, Canada, June 1998), abstract in *Neuroimage* 7, 669 (1998).

G. Idzorek and G. A. Chandler, "Spectral Unfold Techniques for Z-Pinch Implosions," International Conference on Plasma Science (ICOPS) (Raleigh, North Carolina, June 1998).

L. C. Johnson, C. W. Barnes, P. Batistoni, C. Fiore, G. Janeschitz, V. Khripunov, A. Krasilnikov, F. B. Marcus, T. Nishitani, G. Sadler, and V. Zaveriaev, "Neutron Cameras for ITER," 12th Topical Conference High Temperature Plasma Diagnostics (Princeton, New Jersey, June 1998).

M. B. Johnson, "Deep Inelastic Scattering and the Pion Wave Function," Conference on the Structure of Mesons, Baryons, and Nuclei (Cracow, Poland, May 1998).

R. H. Kraus, Jr., E. R. Flynn, M. A. Espy, A. Matlachov, W. C. Overton, Jr., M. V. Peters, and P. F. Ruminer, “First Results for a Novel Superconducting Imaging-Surface Sensor Array,” Applied Superconductivity Conference (Palm Desert, California, September 1998).

R. H. Kraus, Jr., E. R. Flynn, M. A. Espy, A. Matlachov, W. C. Overton, Jr., C. C. Wood, M. V. Peters, and P. F. Ruminer, “First Results for Superconducting Imaging-Surface Sensor Array for Magnetoencephalography,” Biomag98: Advances in Biomagnetic Research (Sendia, Japan, August 1998).

G. A. Kryala, “The Use of High Irradiance Laser for X-Ray Backlighting on Atlas,” 40th Annual Meeting of the Division of Plasma Physics of the American Physical Society (New Orleans, Louisiana, November 1998).

G. A. Kryala, R. P. Johnson, and T. R. Hurry, “A New Interferometer to Measure Preheat in Laser Targets,” 12th Topical Conference High Temperature Plasma Diagnostics (Princeton, New Jersey, June 1998).

N. A. Kurnit, S. A. Letzring, and R. P. Johnson, “A High-Damage-Threshold Pinhole for Glass Fusion Laser Applications,” 3rd Annual International Conference on Solid State Lasers for Application to Inertial Confinement Fusion (Monterey, California, June 1998).

G. A. Kryala, J. B. Workman, S. C. Evans, and T. E. Tierney, “Photocathodes at High Energy: The MTF and Response of Streak Cameras and MCPs at a Few keV X-Ray Energies,” High-Speed Photography and Photonics ’98 (Moscow, Russia, September 1998).

C. Lee, L. G. Stolarczyk, D. L. Baldridge, J. T. Duncan, J. M. Mack, Jr., R. E. Kelly, R. W. Moses, C. R. Smith, K. S. Wilson, and G. D. Arndt, “Electromagnetic Wave Detection and Imaging Technology (EDIT) Hand-Held Metallic/Nonmetallic Land Mine Detector,” 2nd International Conference on the Detection of Abandoned Land Mines (Edinburgh, United Kingdom, October 1998).

M. J. Leitch, “Vector Meson Production and Nuclear Effects in Fermilab E866,” RIKEN-BNL Workshop on Quarkonium Production in Ultra-Relativistic Nuclear Collisions (Brookhaven, New York, September 1998).

M. J. Leitch, “Vector Meson Production and Nuclear Effects in FNAL E866,” Workshop on Charmonium Production in Relativistic Nuclear Collisions (Seattle, Washington, May 1998).

M. J. Leitch, T. C. Awes, M. L. Brooks, C. N. Brown, J. D. Bush, T. A. Carey, T. H. Chang, W. E. Cooper, C. A. Gagliardi, G. T. Garvey, D. F. Geesaman, E. A. Hawker, X. C. He, L. D. Isenhower, S. B. Kaufman, D. M. Kaplan, D. D. Koetke, D. M. Lee, W. M. Lee, N. Makins, P. L. McGaughey, J. M. Moss, B. A. Mueller, P. M. Nord, B. K. Park, V. Papavassiliou, J.-C. Peng, G. Petitt, P. E. Reimer, M. E. Sadler,

P. W. Stankus, W. E. Sondheim, R. S. Towell, R. E. Tribble, M. A. Vasiliev, J. C. Webb, J. L. Willis, D. K. Wise, and G. R. Young, "Vector Meson Production and Nuclear Effects in FNAL E866," 14th International Seminar on High Energy Physics Problems (Dubna, Russia, August 1998).

W. Louis, *et al.* (LSND Collaboration), "Searches For Neutrino Oscillations III: LSND," WEIN'98 (Santa Fe, New Mexico, June 1998).

J. Mack, "Update of Signficant UXO Detection and Remediation Activities," DOE UXO Advisory Board Multi-University Research Iniative (Denver, Colorado, October 1998).

J. Mack, C. Briles, R. Kelly, R. Moses, R. C. Smith, S. K. Wilson, D. Baldridge, J. Duncan, P. Encinias, D. Patrick, G. Stolarczyk, L. Stolarczyk, and G. Arndt, "Landmine Detection using Resonant Microstrip Patch Antennas," 2nd International Conference on the Detection of Abandoned Land Mines (Edinburgh, United Kingdom, October 1998).

J. Mack, S. Caldwell, H. Hsu, and C. Young, "High-Bandwidth Gamma-Ray Inertial Fusion Burn Measurements," 12th Topical Conference High Temperature Plasma Diagnostics (Princeton, New Jersey, June 1998).

R. J. Maqueda, G. A. Wurden, J. L. Terry, and J. A. Stillman, "C-Mod's New Infrared Imaging System," 12th Topical Conference High Temperature Plasma Diagnostics (Princeton, New Jersey, June 1998).

A. Matlachov and R. H. Kraus, Jr., "Base Distance Optimization for SQUID Gradiometers," Applied Superconductivity Conference (Palm Desert, California, September 1998).

A. Matlachov, R. H. Kraus, Jr., M. A. Espy, P. F. Ruminer, and L. G. Atencio, "Sequential Read-Out Architecture for Multichannel SQUID Systems," Applied Superconductivity Conference (Palm Desert, California, September 1998).

B. T. McCuistian, "High Current Density Electrical Connections in the Atlas Pulsed Power Facility in Los Alamos," Texas Technical University Physics Department Colloquium (Texas, November 1998).

R. E. Mischke, "Hyperon Particle Physics at JHF," International Workshop on JHF Science (Tsukuba, Japan, March 1998), in *KEK Proceedings* 98-5, 185 (1998).

R. E. Mischke, "MEGA: A Search for μ to *e*g," International Workshop on JHF Science (Tsukuba, Japan, March 1998), in *KEK Proceedings* 98-5, 185 (1998).

D. S. Montgomery, R. P. Johnson, J. A. Cobble, J. C. Fernández, E. L. Lindman, and K. G. Estabrook, "Characterization of Plasma and Laser Condictions for Single Hot Spot Interaction Experiments," 25th European Conference on Laser Interaction with Matter (Formia, Italy, May 1998).

D. S. Montgomery, H. A. Rose, J. A. Cobble, and R. P. Johnson, "Laser-Plasma Interaction Experiments in a Single Hot Spot," 25th European Conference on Laser Interaction with Matter (Formia, Italy, May 1998).

D. S. Montgomery, H. A. Rose, R. P. Johnson, J. A. Cobble, J. C. Fernández, and E. L. Lindman, "Laser-Plasma Interaction Experiments in a Single Hot Spot," 28th Annual Anomalous Absorption Conference (Bar Harbor, Maine, June 1998).

K. R. Moore, J. R. Frigo, and M. W. Tilden, "Hugin Backup Attitude and Control System," American Geophysical Union (San Francisco, California, December 1998).

K. R. Moore, J. R. Frigo, and M. W. Tilden, "Nanosatellite Robots," DARPA Mesoscale Machines Review (Annapolis, Maryland, October 1998).

J. C. Mosher and R. Leahy, " Recursively Applied and Projected (RAP) Music for Locating Distributed Nondipolar EEG and MEG Sources," Functional Mapping of the Human Brain (Montreal, Canada, June 1998), abstract in *Neuroimage* 7, 680 (1998).

J. C. Mosher, M. E. Spenser, M. X. Huang, R. Leahy, and J. Lewine, "Study of Dipole Localization's Accuracy for MEG and EEG using a Human Skull Phantom," Functional Mapping of the Human Brain (Montreal, Canada, June 1998).

C. Munson, "Plasma-Based Surface Enhancement Research and Development at LANL," 12th International Confrence on High Power Particle Beams (BEAMS '98) (Haifa, Israel, June 1998).

T. J. Murphy, R. A. Lerche, and R. G. Hay, "Drive Symmetry Measurements of Indirectly Driven Implosions on Omega," 12th Topical Conference High Temperature Plasma Diagnostics (Princeton, New Jersey, June 1998).

J. L. Nagle and M. J. Bennett, "Phenomenology of J/Psi and Drell/Yan Production in Heavy Ion Collisions," Annual Meeting of the Division of Nuclear Physics (Santa Fe, New Mexico, October 1998).

J. Oertel, "A Multipurpose Tim-Based Optical Telescope for OMEGA and Trident Upgrades," 12th Topical Conference High Temperature Plasma Diagnostics (Princeton, New Jersey, June 1998).

D. M. Oró, R. D. Fulton, and D. Platts, “Flash X-Ray Radiography on Pegasus,” JOWOG 37 (Joint United States/United Kingdom Working Group) (Los Alamos, New Mexico, February 1998).

D. Oró, R. D. Fulton, J. Stokes, J. Guzik, P. J. Adams, D. Morgan, D. Platts, and A. W. Obst, “Studies of Shock Induced Flows in Strengthless Materials on Pegasus,” International Conference on Plasma Science (ICOPS) (Raleigh, North Carolina, June 1998), abstract in *Abstracts from the 1998 IEEE International Conference on Plasma Science*, 265 (1998).

D. M. Oró, R. J. McKee, M. G. Sheppard, W. L. Atchison, and D. V. Morgan, “Analysis of Radiographs from the Rayleigh-Taylor Mix Experiment on Pegasus using the Bayes Inference Engine,” Nuclear Explosives Code Development Conference (NECDC) (Las Vegas, Nevada, October 1998).

C. R. Peña, K. L. Albright, and G. J. Yates, “High-Speed Cooled CCD Experiments,” Detection and Analysis of Subsurface Objects and Phenomena (Monterey, California, October 1998).

J.-C. Peng, T. C. Awes, M. E. Beddo, M. L. Brooks, C. N. Brown, J. D. Bush, T. A. Carey, T. H. Chang, W. E. Cooper, C. A. Gagliardi, G. T. Garvey, D. F. Geesaman, E. A. Hawker, X. C. He, L. D. Isenhower, S. B. Kaufman, D. M. Kaplan, P. N. Kirk, D. D. Koetke, G. Kyle, D. M. Lee, W. M. Lee, M. J. Leitch, N. Makins, P. L. McGaughey, J. M. Moss, B. A. Mueller, P. M. Nord, B. K. Park, V. Papavassiliou, G. Petitt, P. E. Reimer, M. E. Sadler, P. W. Stankus, W. E. Sondheim, T. N. Thompson, R. S. Towell, R. E. Tribble, M. A. Vasiliev, Y. C. Wang, Z. F. Wang, J. C. Webb, J. L. Willis, D. Wise, and G. R. Young (FNAL E866/NuSea Collaboration), “Measurements of the Light Quark Flavor Asymmetry in the Nucleon Sea,” International Conference on High Energy Physics (1998, Vancouver, Canada, July 1998).

S. I. Pentillä, J. J. Jarmer, T. W. Langston, C.-M. Riedel, D. R. Yeamans, M. E. Beddo, J. R. Comfort, K. K. Craig, C. V. Gaulard, M. A. Espy, T. Kasprzyk, H. Spinka, K. R. Knight, D. Rigsby, M. E. Sadler, E. Six, I. Supek, and G. J. Wagner, “Large NMR Signals and Polarization Asymmetries,” NMR in Polarized Targets (Charlottesville, Virgina, April 1998).

P. E. Reimer, “Light Antiquark Flavor Asymmetry in the Nucleon: FNAL E866,” Invited Seminar at Los Alamos National Laboratory (Los Alamos, New Mexico, March 1998).

P. E. Reimer, “Measurement of the $\bar{d}/\bar{u}$ Asymmetry in the Nucleon,” Fall Meeting of the Division of Nuclear Physics of the American Physical Society (Santa Fe, New Mexico, October 1998), in *Bulletin of the American Physical Society* 43, 1525 (1998).

P. E. Reimer, “A Measurement of the $\bar{d}/\bar{u}$ Asymmetry in the Nucleon Sea,” Invited Seminar at the University of Virginia (Charlottesville, Virginia, April 1998).

P. E. Reimer, “A Measurement of the Light Antiquark Asymmetry in the Nucleon Sea,” Invited Seminar at Argonne National Laboratory (Argonne, Illinois, December 1998).

P. E. Reimer, “A Measurement of the Light Antiquark Asymmetry in the Nucleon Sea,” Invited Seminar at the University of Illinois (Urbana, Illinois, December 1998).

P. E. Reimer, “Measurement of the Light Antiquark Flavor Asymmetry in the Nucleon Sea: FNAL E866,” Pheno-CETQ Symposium ’98: From Non-Perturbative QCD to New Physics (Madison, Wisconsin, March 1998).

P. E. Reimer, “Measurement of the Nuclear Dependence of the Phi and Low Mass Muon Pair Continuum,” Fall Meeting of the Division of Nuclear Physics of the American Physical Society (Santa Fe, New Mexico, October 1998), in *Bulletin of the American Physical Society* 43, 1567 (1998).

P. E. Reimer, “QCD: Bound States,” Fermilab Users Meeting (Batavia, Illinois, July 1998).

R. E. Reinovsky, W. E. Anderson, W. L. Atchison, C. A. Ekdahl, R. J. Faehl, D. A. Clark, I. R. Lindemuth, D. Morgan, M. Murillo, A. M. Buyko, O. M. Burenkov, V. K. Chernyshev, S. F. Garanin, Y. N. Gorbachev, B. E. Grenivech, V. V. Zmushko, G. G. Ivanova, A. I. Kuziev, V. N. Mokhov, P. N. Nizovtsev, A. A. Petrukhin, A. I. Pischurov, V. P. Solovyev, N. V. Sokolova, V. N. Sofronov, A. I. Startsev, and V. B. Yakubov, “Experimental Observation of Rayleigh-Taylor Modes in Solids with Strength,” International Conference on Plasma Science (ICOPS) (Raleigh, North Carolina, June 1998), abstract in *Abstracts from the 1998 IEEE International Conference on Plasma Science*, 245 (1998).

B. R. Schlei, “Bose-Einstein Correlations and the Equation of State of Nuclear Matter in Relativistic Heavy-Ion Collisions,” Correlations and Fluctuations Workshop (M’atrah’aza, Hungary, June 1998).

B. R. Schlei, “How Much Can We Learn about the Equation of State from HBT Analysis?’’ INT Spring Program: Probes on Dense Matter in Ultrarelativistic Heavy Ion Collisions (Seattle, Washington, March 1998).

B. R. Schlei, “Measuring the Space-Time Extent of Nuclear Collisions using Two-Particle Correlations,” Fall Meeting of the Division of Nuclear Physics of the American Physical Society (Santa Fe, New Mexico, October 1998).

B. R. Schlei, “Relativistic Hydrodynamics,” PHENIX Collaboration Meeting (Ames, Iowa, June 1998).

B. R. Schlei and D. Strottman, “Sensitivity of Hydrodynamic Results to the Equation of State at SPS Energies,” Fall Meeting of the Division of Nuclear Physics of the American Physical Society (Santa Fe, New Mexico, October 1998).

D. W. Scudder, “Experimental Techniques Using the HDZP-11 Generator,” ABC’s of Z’s Workshop at the University of Nevada (Reno, Nevada, May 1998).

G. Selwyn, “Dry Decontamination of Chenical and Biological Warfare Agents using an Atmospheric Pressure Plasma Jet,” Air Component Command (Korea, 1998).

G. Selwyn, “New Methods for Contamination Control and Dry Cleaning of Silicon Wafers,” 4th International Symposium on Ultra-Clean Processing of Silicon Surfaces (Ostend, Belgium, September 1998).

G. Selwyn, “Real Time, *in-situ* Imaging Detection and Control of Process-Generated Particulate Contamination,” Rocky Mountain Regional Meeting of the American Vacuum Society (Denver, Colorado, August 1998).

J. S. Shlachter, “Dense Z-Pinch Research at Los Alamos, Theory and Experiment,” ABC’s of Z’s Workshop at the University of Nevada (Reno, Nevada, May 1998).

J. S. Shlachter, P. J. Adams, W. L. Atchison, R. R. Bartsch, J. F. Benage, J. C. Cochrane, W. L. Coulter, C. A. Ekdahl, R. J. Faehl, R. D. Fulton, J. Guzik, D. Holtkamp, M. E. Jones, R. Keinigs, N. S. P. King, H. Lee, I. R. Lindemuth, D. V. Morgan, A. W. Obst, H. Oona, D. Oró, D. Platts, R. E. Reinovsky, G. Rodriguez, G. M. Sandoval, D. W. Scudder, M. Sheppard, D. S. Sorenson, J. L. Stokes, and A. Taylor, “Overview of the Pegasus II Experimental Program,” International Conference on Plasma Science (ICOPS) (Raleigh, North Carolina, June 1998), abstract in *Abstracts from the 1998 IEEE International Conference on Plasma Science*, 243 (1998).

J. L. Stokes, “Material Failure and Inertial Instabilities in a Shocked and Imploded Cylindrical Aluminum Sample,” International Conference on Plasma Science (ICOPS) (Raleigh, North Carolina, June 1998).

J. L. Stokes, “Use of the Pegasus Z-Pinch to Study Inertial Instabilities and Material Failure in Aluminum,” JOWOG 32-P (Joint United States/ United Kingdom Working Group) (Livermore, California, March 1998).

J. P. Sullivan, “Two-Particle Correlations from CERN Experiment NA44,” in *Abstracts of Papers of the American Chemical Society* 215, 69-NUCL (1998).

J. Sullivan, “Two Particle Correlations from NA44,” CRIS’98 Conference (Catania, Italy, June 1998).

J. Sullivan, “Two Particle Correlation Results from NA44,” INT Workshop on Particle Spectra and Correlation (HBT) (Seattle, Washington, March 1998).

J. Sullivan, “Simulations and Performance of the MVD in PHENIX,” poster presentation at the IEEE Nuclear Science Symposium and Medical Imaging Conference (Toronto, Canada, November 1998).

T. C. Terwilliger and J. R. Berendzen, “Automated Structure Determination and Structural Genomics,” Structural Genomics Conference (Avelon, October 1998).

T. C. Terwilliger and J. R. Berendzen, “Exploring and Eploiting Protein Structure Space,” Structural Genomics (Argonne, New York, January 1998).

T. C. Terwilliger and J. R. Berendzen, “Exploring Structure Space: A Protein Structure Initiative,” Structural and Functional Genomics (Trieste, Italy, May 1998).

T. C. Terwilliger and J. R. Berendzen, “Protein Crystallography: From X-Ray Diffraction Spots to a Three-Dimensional Image,” Optical Society of America (Kona, Hawaii, June 1998).

Y. C. F. Thio, “X-Ray Diagnostics for an MTF Initial Target Plasma,” International Conference on Plasma Science (ICOPS) (Raleigh, North Carolina, June 1998).

R. S. Towell, T. C. Awes, M. E. Beddo, C. N. Brown, J. D. Bush, T. A. Carey, T. H. Chang, W. E. Cooper, C. A. Gagliardi, G. T. Garvey, D. F. Geesaman, E. A. Hawker, X. C. He, L. D. Isenhower, S. B. Kaufman, D. M. Kaplan, P. N. Kirk, D. D. Koetke, G. Kyle, D. M. Lee, W. M. Lee, M. J. Leitch, N. Makins, P. L. McGaughey, J. M. Moss, B. A. Mueller, P. M. Nord, B. K. Park, V. Papavassiliou, J.-C. Peng, G. Petitt, P. E. Reimer, M. E. Sadler, P. W. Stankus, W. E. Sondheim, T. N. Thompson, R. S. Towell, R. E. Tribble, M. A. Vasiliev, Y. C. Wang, Z.F. Wang, J. C. Webb, J. L. Willis, D. K. Wise, and G. R. Young, “New Results from Fermilab E866: Flavor Asymmetry in the Nucleon Sea and Nuclear Effects in J/Psi Production,” 33rd Moriond Conference (Moriond, France, March 1998), in *QCD and High Energy Hadronic Interactions*, J. T. T. Van, Ed., (Editions Frontiere, 1998).

H. van Hecke, "Extracting Global Parameters from Ultrarelativistic Heavy-Ion Collisions," Nuclear Shapes and Motions Symposium (Santa Fe, New Mexico, October 1998).

W. S. Varnum, C. W. Barnes, R. E. Chrien, N. D. Delamater, J. R. Duke, N. E. Elliott, P. L. Gobby, V. M. Gomez, J. E. Moore, G. D. Pollak, R. G. Watt, J. D. Colvin, R. A. Lerche, and T. W. Phillips, "Double-Shell Capsules as a Promising Alternate Design for ICF," 40th Annual Meeting of the Division of Plasma Physics of the American Physical Society (New Orleans, Louisiana, November 1998).

M. A. Vasiliev, T. C. Awes, M. E. Beddo, C. N. Brown, J. D. Bush, T. A. Carey, T. H. Chang, W. E. Cooper, C. A. Gagliardi, G. T. Garvey, D. F. Geesaman, E. A. Hawker, X. C. He, L. D. Isenhower, S. B. Kaufman, D. M. Kaplan, P. N. Kirk, D. D. Koetke, G. Kyle, D. M. Lee, W. M. Lee, M. J. Leitch, N. Makins, P. L. McGaughey, J. M. Moss, B. A. Mueller, P. M. Nord, B. K. Park, V. Papavassiliou, J.-C. Peng, G. Petitt, P. E. Reimer, M. E. Sadler, J. Selden, P. W. Stankus, W. E. Sondheim, T. N. Thompson, R. S. Towell, R. E. Tribble, Y. C. Wang, Z. F. Wang, J. C. Webb, J. L. Willis, D. Wise, and G. R. Young, "Measurement of the Flavor Asymmetry in the Nucleon Sea," Lake Louise Winter Institute on Quantum Chromodyanmics (Lake Louise, Canada, February 1998).

L. Veeser, C. Ekdahl, H. Oona, P. Rodriguez, G. Schmitt, J. Solem, S. Younger, S. Baker, C. Hudson, W. Lewis, B. Marshall, W. Turley, A. Bykov, G. Boriskov, M. Dolotenko, N. Egorov, N. Kolokol'chikov, M. Kozlov, Y. Kurpathkin, and A. Volkov, "Isentropic Compression of Argon and Krypton using an MC1 Flux Compression Generator," 8th International Conference on Megagauss Magnetic Field Generation and Related Topics (Tallahassee, Florida, October 1998).

L. Veeser, C. Ekdahl, H. Oona, P. Rodriguez, G. Schmitt, J. Solem, S. Younger, S. Baker, W. Lewis, W. Turley, A. Bykov, G. Boriskov, M. Dolotenko, N. Kolokol'chikov, M. Kozlov, Y. Kurpathkin, A. Volkov, and N. Yegorov, "Isentropic Compression of Argon and Krypton," JOWOG 37 (Joint United States/United Kingdom Working Group) (Los Alamos, New Mexico, February 1998).

R. G. Watt, C. W. Barnes, R. E. Chrien, N. D. Delamater, J. R. Duke, N. E. Elliott, P. L. Gobby, V. M. Gomez, J. E. Moore, G. D. Pollak, W. S. Varnum, J. D. Colvin, R. A. Lerche, and T. W. Phillips, "Double-Shell Capsule Implosions at NOVA and OMEGA," 40th Annual Meeting of the Division of Plasma Physics of the American Physical Society (New Orleans, Louisiana, November 1998).

C. H. Wendt, D. P. Butt, K. S. Lackner, and H.-J. Ziock, "Thermodynamic Considerations of using Chlorides to Accelerate the Carbonate Formation from Magnesium Silicates," 4th International Conference on Greenhouse Gas Control Technologies (GHGT-4) (Interlaken, Switzerland, August–September 1998).

B. Wood, “Surface Cratering Behavior of High Power Ion Beams,” 12th International Confrence on High Power Particle Beams (BEAMS ’98) (Haifa, Israel, June 1998).

W. M. Wood, B. Wright, D. Oró, R. D. Fulton, and D. Moir, “Dynamical Measurements of Plasmas Generated by Relativistic Electrons Colliding with Metal Target,” International Conference on Plasma Science (ICOPS) (Raleigh, North Carolina, June 1998).

J. Workman, T. Tierney, S. Evans, G. Kyrala, and J. Benage, Jr., “1-D X-Ray Microscope for Shock Velocity Measurements in High-Density Aluminum Plasmas,” 12th Topical Conference High Temperature Plasma Diagnostics (Princeton, New Jersey, June 1998).

J. Workman, T. Tierney, S. Evans, G. Kyrala, and J. Benage, Jr., “Spatially- Temporarily-Resolved Shock Densities using a 1-D X-Ray Microscope,” 12th Topical Conference High Temperature Plasma Diagnostics (Princeton, New Jersey, June 1998).

F. Wysocki, “Characterization of a Target Plasma for MTF,” 8th International Conference on Megagauss Magnetic Field Generation and Related Topics (Tallahassee, Florida, October 1998).

F. Wysocki, “Possibilties for a Spheromak Target for Magnetized Target Fusion,” Innovative Confinement Concepts Worshop (Princeton, New Jersey, April 1998).

G. Xu and J.-C. Peng, “Gluon Polarization and Dihadron Production at RHIC,” RIKEN BNL Research Center Workshop (Upton, New York, April 1998), in *Proceedings of RIKEN BNL Research Center Workshop* 7, 131 (1998).

H.-J. Ziock, “Diamond Detector R&D,” Workshop on Physics and Detectors for Future *e+e-* Linear Colliders (Keystone, Colorado, September 1998).

H.-J. Ziock, D. P. Butt, K. S. Lackner, and C. H. Wendt, “The Need and Options Available for Permanent CO_2 Disposal,” AIChE Topical Conference on Pollution Prevention and Environmental Risk Reduction (Miami Beach, Florida, November 1998).